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Research and Development Labs, Culver City, CA

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13. ABSTRACT *(Maximum 200 words)*
The purpose of this program is to develop the basis for continuing research of interest to the Air Force at the institution of the faculty member; to stimulate continuing relations among faculty members and professional peers in the Air Force to enhance the research interests and capabilities of scientific and engineering educators; and to provide follow-on funding for research of particular promise that was started at an Air Force laboratory under the Summer Faculty Research Program. Each participant provided a report of their research, and these reports are consolidated into this annual report.

14. SUBJECT TERMS
AIR FORCE RESEARCH, AIR FORCE, ENGINEERING, LABORATORIES, REPORTS, UNIVERSITIES

15. NUMBER OF PAGES

16. PRICE CODE

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UNITED STATES AIR FORCE

SUMMER RESEARCH PROGRAM -- 1993

SUMMER RESEARCH EXTENSION PROGRAM FINAL REPORTS

VOLUME 1A

PROGRAM MANAGEMENT REPORT
ARMSTRONG LABORATORY

RESEARCH & DEVELOPMENT LABORATORIES

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Submitted to:

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

Bolling Air Force Base

Washington, D.C.

November 1994

PREFACE

This volume is part of a five-volume set that summarizes the research of participants in the 1993 AFOSR Summer Research Extension Program (SREP). The current volume, Volume 1A of 5, presents the final reports of SREP participants at Armstrong Laboratory.

Reports presented in this volume are arranged alphabetically by author and are numbered consecutively -- e.g., 1-1, 1-2, 1-3; 2-1, 2-2, 2-3, with each series of reports preceded by a 35 page management summary. Reports in the five-volume set are organized as follows:

VOLUME	TITLE
1A	Armstrong Laboratory (part one)
1B	Armstrong Laboratory (part two)
2	Phillips Laboratory
3	Rome Laboratory
4A	Wright Laboratory (part one)
4B	Wright Laboratory (part two)
5	Arnold Engineering Development Center Frank J. Seiler Research Laboratory Wilford Hall Medical Center

1993 SREP FINAL REPORTS

Armstrong Laboratory

VOLUME 1A

1993 SREP FINAL REPORTS

Armstrong Laboratory

VOLUME 1B

1993 SREP FINAL REPORTS

Phillips Laboratory

VOLUME 2

Report #	Report Title Author's University	Report Author
1	Optimal Passive Damping of a Complex Strut-Built Structure Iowa State University, Ames, IA	Dr. Joseph Baumgarten Mechanical Engineering PL/VT
2	Theoretical and Experimental Studies on the Effects of Low-Energy X-Rays on Elec University of Arizona, Tucson, AZ	Dr. Raymond Bellem Electrical & Computer Engineering PL/VT
3	Ultrawideband Antennas with Low Dispersion for Impulse Radars University of Alabama, Huntsville, AL	Dr. Albert Biggs Electrical Engineering PL/WS
4	Experimental Neutron Scattering Investigations of Liquid-Crystal Polymers Arkansas Technology University, Russellville, AR	Dr. David Elliott Engineering PL/RK
5	High Temperature Spectroscopy of Alkali Metal Vapors for Solar to Thermal Energy University of Iowa, Iowa City, IA	Mr. Paul Erdman Physics and Astronomy PL/RK
6	A Detailed Investigation of Low-and High-Power Arcjet Plume Velocity Profiles Us University of Southern California, Los Angeles, CA	Dr. Daniel Erwin Aerospace Engineering PL/RK
7	Measurements of Ion-Molecule Reactions at High Temperatures University of Puerto Rico, Mayaguez, PR	Dr. Jeffrey Friedman Physics PL/GP
8	Final Design and Construction of Lidar Receiver for the Starfire Optical Range Georgia Institute of Technology, Atlanta, GA	Dr. Gary Gimmestad Research Institute PL/LI
9	Dynamics of Gas-Phase Ion-Molecule Reactions Carnegie Mellon University, Pittsburgh, PA	Dr. Susan Graul Chemistry PL/WS
10	A Numerical Approach to Evaluating Phase Change Material Performance in Infrared University of Texas, San Antonio, TX	Mr. Steven Griffin Engineering PL/VT
11	An Analysis of ISAR Imaging and Image Simulation Technologies and Related Post University of Nevada, Reno, NV	Dr. James Henson Electrical Engineering PL/WS
12	Optical and Clear Air Turbulence Worcester Polytechnic Institut, Worcester, MA	Dr. Mayer Humi Mathematics PL/LI
13	Rotational Dynamics of Lageos Satellite North Carolina State University, Raleigh, NC	Dr. Arkady Kheyfets Mathematics PL/LI
14	Study of Instabilities Excited by Powerful HF Waves for Efficient Generation of Polytechnic University, Farmingdale, NY	Dr. Spencer Kuo Electrical Engineering PL/GP

1993 SREP FINAL REPORTS

Phillips Laboratory

VOLUME 2
cont'd

1993 SREP FINAL REPORTS

Rome Laboratory

VOLUME 3

1993 SREP FINAL REPORTS

Wright Laboratory

VOLUME 4A

Wright Laboratory

VOLUME 4A
cont'd

1993 SREP FINAL REPORTS

Wright Laboratory

VOLUME 4B

Wright Laboratory

VOLUME 4B
cont'd

1993 SREP FINAL REPORTS

VOLUME 5

1993 SUMMER RESEARCH EXTENSION PROGRAM (SREP) MANAGEMENT REPORT

1.0 BACKGROUND

Under the provisions of Air Force Office of Scientific Research (AFOSR) contract F49620-90-C-0076, September 1990, Research & Development Laboratories (RDL), an 8(a) contractor in Culver City, CA, manages AFOSR's Summer Research Program. This report is issued in partial fulfillment of that contract (CLIN 0003AC).

The Summer Research Extension Program (SREP) is one of four programs AFOSR manages under the Summer Research Program. The Summer Faculty Research Program (SFRP) and the Graduate Student Research Program (GSRP) place college-level research associates in Air Force research laboratories around the United States for 8 to 12 weeks of research with Air Force scientists. The High School Apprenticeship Program (HSAP) is the fourth element of the Summer Research Program, allowing promising mathematics and science students to spend two months of their summer vacations working at Air Force laboratories within commuting distance from their homes.

SFRP associates and exceptional GSRP associates are encouraged, at the end of their summer tours, to write proposals to extend their summer research during the following calendar year at their home institutions. AFOSR provides funds adequate to pay for 75 SREP subcontracts. In addition, AFOSR has traditionally provided further funding, when available, to pay for additional SREP proposals, including those submitted by associates from Historically Black Colleges and Universities (HBCUs) and Minority Institutions (MIs). Finally, laboratories may transfer internal funds to AFOSR to fund additional SREPs. Ultimately the laboratories inform RDL of their SREP choices, RDL gets AFOSR approval, and RDL forwards a subcontract to the institution where the SREP associate is employed. The subcontract (see Appendix 1 for a sample) cites the SREP associate as the principal investigator and requires submission of a report at the end of the subcontract period.

Institutions are encouraged to share costs of the SREP research, and many do so. The most common cost-sharing arrangement is reduction in the overhead, fringes, or administrative charges institutions would normally add on to the principal investigator's or research associate's labor. Some institutions also provide other support (e.g., computer run time, administrative assistance, facilities and equipment or research assistants) at reduced or no cost.

When RDL receives the signed subcontract, we fund the effort initially by providing 90% of the subcontract amount to the institution (normally $18,000 for a $20,000 SREP). When we receive the end-of-research report, we evaluate it administratively and send a copy to the laboratory for a technical evaluation. When the laboratory notifies us the SREP report is acceptable, we release the remaining funds to the institution.

2.0 THE 1993 SREP PROGRAM

SELECTION DATA: A total of 719 faculty members (SFRP Associates) and 286 graduate students (GSRP associates) applied to participate in the 1992 Summer Research Program. From these applicants 185 SFRPs and 121 GSRPs were selected. The education level of those selected was as follows:

1992 SRP Associates, by Degree			
SFRP		GSRP	
PHD	MS	MS	BS
179	6	52	69

Of the participants in the 1992 Summer Research Program 90 percent of SFRPs and 25 percent of GSRPs submitted proposals for the SREP. Ninety proposals from SFRPs and ten from GSRPs were selected for funding, which equates to a selection rate of 54% of the SFRP proposals and of 34% for GSRP proposals.

1993 SREP: Proposals Submitted vs. Proposals Selected			
	Summer 1992 Participants	Submitted SREP Proposals	SREPs Funded
SFRP	185	167	90
GSRP	121	29	10
TOTAL	306	196	100

The funding was provided as follows:

Contractual slots funded by AFOSR	75
Laboratory funded	14
Additional funding from AFOSR	11
Total	100

Six HBCU/MI associates from the 1992 summer program submitted SREP proposals; six were selected (none were lab-funded; all were funded by additional AFOSR funds).

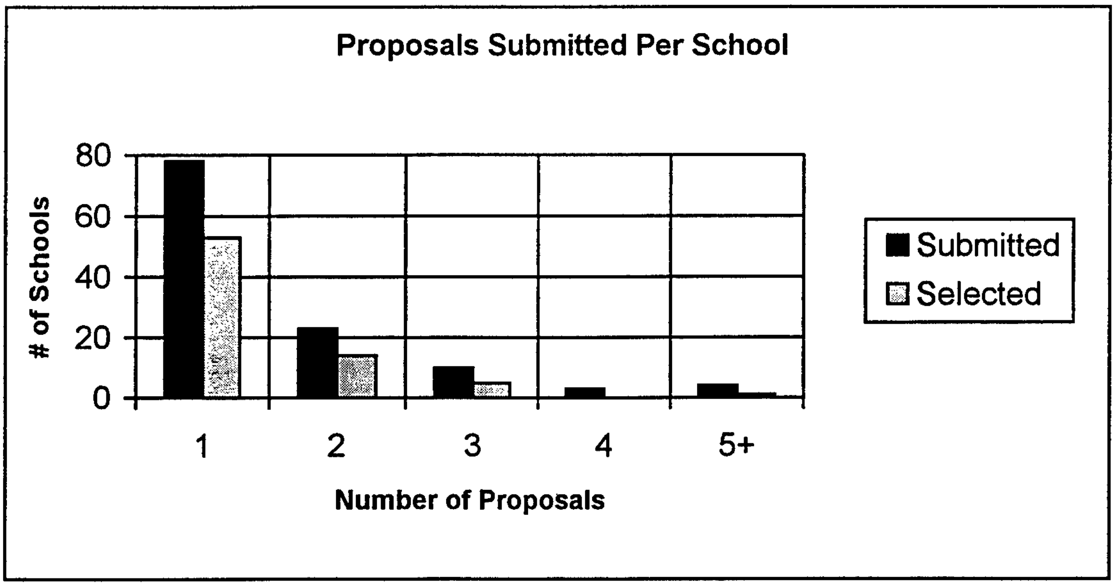
Proposals Submitted and Selected, by Laboratory		
	Applied	Selected
Air Force Civil Engineering Laboratory	9	4
Armstrong Laboratory	41	19
Arnold Engineering Development Center	12	4
Frank J. Seiler Research Laboratory	6	3
Phillips Laboratory	33	19
Rome Laboratory	31	13
Wilford Hall Medical Center	2	1
Wright Laboratory	62	37
TOTAL	196	100

Note: Phillips Laboratory funded 3 SREPs; Wright Laboratory funded 11; and AFOSR funded 11 beyond its contractual 75.

The 306 1992 Summer Research Program participants represented 135 institutions.

Institutions Represented on the 1992 SRP and 1993 SREP		
Number of schools represented in the Summer 92 Program	Number of schools represented in submitted proposals	Number of schools represented in Funded Proposals
135	118	73

Forty schools had more than one participant submitting proposals.



The selection rate for the 78 schools submitting 1 proposal (68%) was better than those submitting 2 proposals (61%), 3 proposals (50%), 4 proposals (0%) or 5+ proposals (25%). The 4 schools that submitted 5+ proposals accounted for 30 (15%) of the 196 proposals submitted.

Of the 196 proposals submitted, 159 offered institution cost sharing. Of the funded proposals which offered cost sharing, the minimum cost share was $1000.00, the maximum was $68,000.00 with an average cost share of $12,016.00.

Proposals and Institution Cost Sharing		
	Proposals Submitted	Proposals Funded
With cost sharing	159	82
Without cost sharing	37	18
Total	196	100

The SREP participants were residents of 41 different states. Number of states represented at each laboratory were:

States Represented, by Proposals Submitted/Selected per Laboratory		
	Proposals Submitted	Proposals Funded
Air Force Civil Engineering Laboratory	8	4
Armstrong Laboratory	21	13
Arnold Engineering Development Center	5	2
Frank J. Seiler Research Laboratory	5	3
Phillips Laboratory	16	14
Rome Laboratory	14	7
Wilford Hall Medical Center	2	1
Wright Laboratory	24	20

Eleven of the 1993 SREP Principal Investigators also participated in the 1992 SREP.

<u>ADMINISTRATIVE EVALUATION</u>: The administrative quality of the SREP associates' final reports was satisfactory. Most complied with the formatting and other instructions provided to them by RDL. Ninety seven final reports and two interim reports have been received and are included in this report. The subcontracts were funded by $1,991,623.00 of Air Force money. Institution cost sharing totaled $985,353.00.

TECHNICAL EVALUATION: The form used for the technical evaluation is provided as Appendix 2. ninety-two evaluation reports were received. Participants by laboratory versus evaluations submitted is shown below:

	Participants	Evaluations	Percent
Air Force Civil Engineering Laboratory	*	*	*
Armstrong Laboratory	23[1]	20	95.2
Arnold Engineering Development Center	4	4	100
Frank J. Seiler Research Laboratory	3	3	100
Phillips Laboratory	19[2]	18	100
Rome Laboratory	13	13	100
Wilford Hall Medical Center	1	1	100
Wright Laboratory	37	34	91.9
Total	100[3]	93	95.9

*AFCEL was combined with Wright Laboratory's Flight Dynamics Directorate and Armstrong Laboratories Environics Directorate in 1993. All four of AFCEL's SREP awards went to Armstrong Laboratories Environics Directorate, and their reports are included with Armstrong Lab.

Notes:

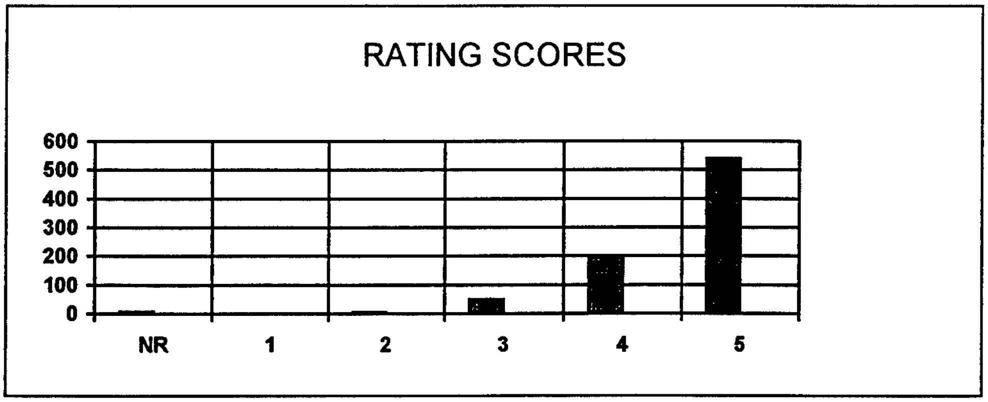
1: Research on two of the final reports was incomplete as of press time so there aren't any technical evaluations on them to process, yet. Percent complete is based upon 20/21=95.2%

2: One technical evaluation was not completed because one of the final reports was incomplete as of press time. Percent complete is based upon 18/18=100%

3: See notes 1 and 2 above. Percent complete is based upon 93/97=95.9%

The number of evaluations submitted for the 1993 SREP (95.9%) shows a marked improvement over the 1992 SREP submittals (65%).

PROGRAM EVALUATION: Each laboratory focal point evaluated ten areas (see Appendix 2) with a rating from one (lowest) to five (highest). The distribution of ratings was as follows:

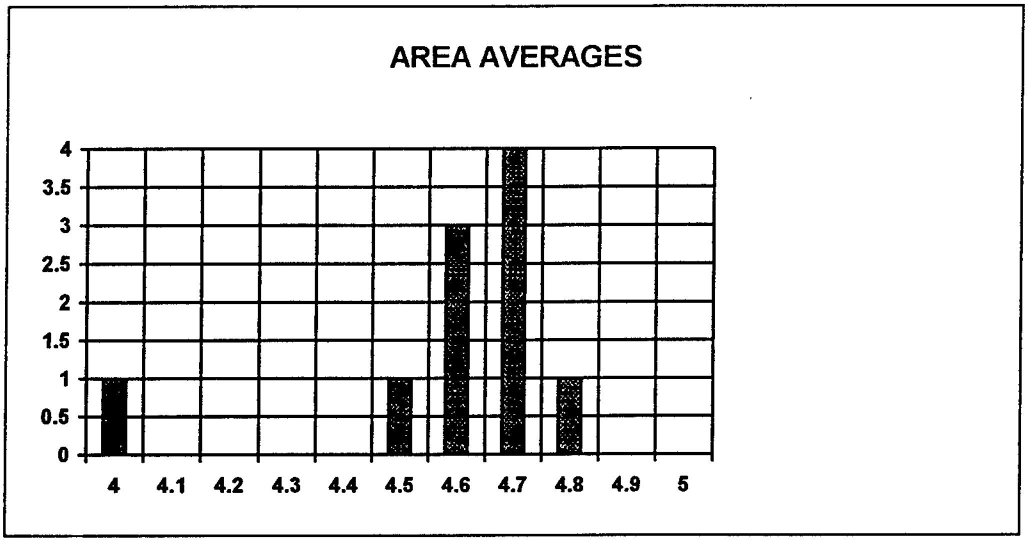


Rating	Not Rated	1	2	3	4	5
# Responses	7	1	7	62 (6%)	226 (25%)	617 (67%)

The 8 low ratings (one 1 and seven 2's) were for question 5 (one 2) "The USAF should continue to pursue the research in this SREP report" and question 10 (one 1 and six 2's) "The one-year period for complete SREP research is about right", in addition over 30% of the threes (20 of 62) were for question ten. The average rating by question was:

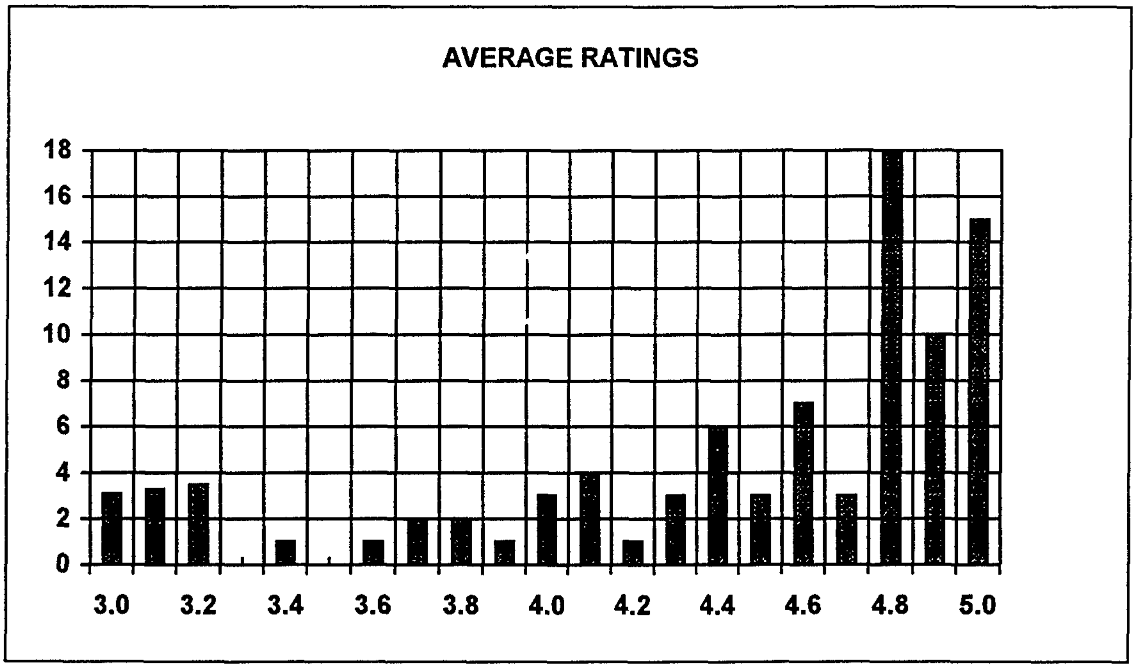
Question	1	2	3	4	5	6	7	8	9	10
Average	4.6	4.6	4.7	4.7	4.6	4.7	4.8	4.5	4.6	4.0

The distribution of the averages was:



Area 10 "the one-year period for complete SREP research is about right" had the lowest average rating (4.1). The overall average across all factors was 4.6 with a small sample standard deviation of 0.2. The average rating for area 10 (4.1) is approximately three sigma lower than the overall average (4.6) indicating that a significant number of the evaluators feel that a period of other than one year should be available for complete SREP research.

The average ratings ranged from 3.4 to 5.0. The overall average for those reports that were evaluated was 4.6. Since the distribution of the ratings is not a normal distribution the average of 4.6 is misleading. In fact over half of the reports received an average rating of 4.8 or higher. The distribution of the average report ratings is as shown:



It is clear from the high ratings that the laboratories place a high value on AFOSR's Summer Research Extension Programs.

3.0 SUBCONTRACTS SUMMARY

Table 1 provides a summary of the SREP subcontracts. The individual reports are published in volumes as shown:

Laboratory	Volume
Air Force Civil Engineering Laboratory	*
Armstrong Laboratory	1
Arnold Engineering Development Center	5
Frank J. Seiler Research Laboratory	5
Phillips Laboratory	2
Rome Laboratory	3
Wilford Hall Medical Center	5
Wright Laboratory	4A, 4B

*AFCEL was combined with Wright Laboratory's Flight Dynamics Directorate and Armstrong Laboratories Environics Directorate in 1993. All four of AFCEL's SREP awards went to Armstrong Laboratories Environics Directorate, and their reports are included with Armstrong Lab.

1993 SREP SUB-CONTRACT DATA

TABLE 1: SUBCONTRACTS SUMMARY

Report Author Author's University	Author's Degree	Sponsoring Lab	Performance Period		Contract Amount Univ. Cost Share
Abbott , Ben Electrical Engineering Vanderbilt University, Nashville, TN	M.S.	AEDC/	01/01/93	12/31/93	$19619.00 $0.00
Alberts , Thomas Mechanical Engineering Old Dominion University, Norfolk, VA	PhD	FJSRL/	01/01/93	04/15/94	$20000.00 $8000.00
Avula , Xavier Mechanical & Aerospace Engineering University of Missouri, Rolla, MO	PhD	AL/AO	01/01/93	04/15/94	$20000.00 $1836.00
Balakrishan , S. Mechanical & Aerospace Engineering University of Missouri, Rolla, MO	PhD	WL/MN	12/01/92	12/14/93	$20000.00 $3996.00
Baumgarten , Joseph Mechanical Engineering Iowa State University, Ames, IA	PhD	PL/VT	01/01/93	04/01/94	$19916.00 $9083.00
Bayard , Jean-Pierre Electrical & Electronic Engineering California State University, Sacramento, CA	PhD	RL/ER	01/01/93	12/31/93	$20000.00 $7423.00
Bellem , Raymond Electrical & Computer Engineering University of Arizona, Tucson, AZ	PhD	PL/VT	01/01/93	02/28/94	$19956.00 $0.00
Biegl , Csaba Electrical Engineering Vanderbilt University, Nashville, TN	PhD	AEDC/	01/01/93	12/31/93	$19999.00 $0.00
Biggs , Albert Electrical Engineering University of Alabama, Huntsville, AL	PhD	PL/WS	01/01/93	12/31/93	$19975.00 $0.00
Burkey , Theodore Chemistry Memphis State University, Memphis, TN	PhD	WL/MN	01/01/93	12/31/93	$20000.00 $18648.00
Burkholder , Robert Electrical Engineering Ohio State University, Columbus, OH	PhD	WL/AA	01/01/93	12/31/93	$20000.00 $6727.00
Callens, Jr. , Eugene Mechanical and Industrial Engineer Louisiana Tech University, Ruston, LA	PhD	WL/MN	01/01/93	12/31/93	$20000.00 $5700.00
Chapman , Gary Mechnical Engineering University of California, Berkeley, CA	PhD	WL/MN	01/01/93	12/31/94	$20000.00 $0.00
Chen , Chien-In Electrical Engineering Wright State University, Dayton, OH	PhD	WL/EL	01/01/93	12/31/93	$20000.00 $32065.00
Chen , Jer-sen Computer Science & Engineering Wright State University, Dayton, OH	PhD	AL/CF	01/01/93	12/31/93	$20000.00 $31763.00

1993 SREP SUB-CONTRACT DATA

Report Author Author's University	Author's Degree	Sponsoring Lab	Performance Period		Contract Amount Univ. Cost Share
Chen , Pinyuen Mathematics Syracuse University, Syracuse, NY	PhD	RL/IR	01/01/93	12/31/93	$20000.00 $0.00
Chow , Joe Industrial and Systems Engineering Florida International University, Miami, FL	PhD	WL/FI	01/01/93	01/14/94	$20000.00 $2500.00
Christensen , Thomas Physics University of Colorado, Colorado Springs, CO	PhD	FJSRL/	01/01/93	12/31/93	$20000.00 $5390.00
Collicott , Steven Aeronautics and Astronautical Engineering Purdue University, West Lafayette, IN	PhD	WL/FI	01/01/93	12/31/93	$20000.00 $13307.00
Cooke , Nancy Psychology New Mexico State University, Las Cruces, NM	PhD	AL/HR	01/01/93	12/31/93	$20000.00 $6178.00
Daley , Michael Electrical Engineering Memphis State, Memphis, TN	PhD	WHMC/	01/01/93	12/31/93	$20000.00 $18260.00
Davidson , Jennifer Electrical Engineering Iowa State University, Ames, IA	PhD	WL/MN	01/01/93	02/28/94	$19999.00 $0.00
Deivanayagam , Subramaniam Industrial Engineering Tennessee Technological University, Cookeville, TN	PhD	AL/HR	02/01/93	12/31/93	$20000.00 $12491.00
Elliott , David Engineering Arkansas Technology University, Russellville, AR	PhD	PL/RK	10/01/92	08/15/93	$20000.00 $50271.00
Erdman , Paul Physics and Astronomy University of Iowa, Iowa City, IA	M.S.	PL/RK	01/01/93	12/31/93	$20000.00 $26408.00
Ervin , Jamie Mechanical and Aerospace Engineering University of Dayton, Dayton, OH	PhD	WL/ML	01/01/93	12/31/93	$18632.00 $3000.00
Erwin , Daniel Aerospace Engineering University of Southern California, Los Angeles, CA	PhD	PL/RK	01/01/93	12/31/93	$19962.00 $12696.00
Ewert , Dan Electrical Engineering North Dakota State University, Fargo, ND	PhD	AL/AO	01/01/93	12/31/93	$20000.00 $2100.00
Farmer , Barry Materials Science and Engineering University of Virginia, Charlottesville, VA	PhD	WL/ML	01/01/93	02/28/94	$20000.00 $2000.00
Foo , Simon Electrical Engineering Florida State University, Tallahassee, FL	PhD	WL/MN	01/01/93	12/31/93	$19977.00 $0.00

1993 SREP SUB-CONTRACT DATA

Report Author Author's University	Author's Degree	Sponsoring Lab	Performance Period		Contract Amount Univ. Cost Share
Friedman , Jeffrey Physics University of Puerto Rico, Mayaguez, PR	PhD	PL/GP	01/01/93	12/31/93	$20000.00 $10233.00
Gerstman , Bernard Physics Florida International University, Miami, FL	PhD	AL/OE	01/01/93	04/30/94	$19947.00 $2443.00
Gillman , Ann Chemistry Eastern Kentucky University, Richmond, KY	M.S.	WL/PO	01/01/93	12/31/93	$20000.00 $15618.00
Gimmestad , Gary Research Institute Georgia Institute of Technology, Atlanta, GA	PhD	PL/LI	01/01/93	12/31/93	$20000.00 $0.00
Gould , Richard Mechanical and Aerospace Engineering North Carolina State University, Raleigh, NC	PhD	WL/PO	01/01/93	12/31/93	$20000.00 $8004.00
Graham , Gary Mechanical Engineering Ohio University, Athens, OH	PhD	WL/FI	01/01/93	12/31/93	$20000.00 $5497.00
Gramoll , Kurt Aerospace Engineering Georgia Institute of Technology, Atlanta, GA	PhD	AEDC/	01/01/93	12/31/93	$19707.00 $14552.00
Graul , Susan Chemistry Carnegie Mellon University, Pittsburgh, PA	PhD	PL/WS	01/01/93	03/31/94	$20000.00 $0.00
Griffin , Steven Engineering University of Texas, San Antonio, TX	M.S.	PL/VT	01/01/93	12/31/93	$20000.00 $0.00
Grubbs , Elmer Electrical Engineering New Mexico Highlands University, Las Vegas, NM	PhD	WL/AA	01/01/93	12/31/93	$20000.00 $6747.00
Gupta , Pushpa Mathematics University of Maine, Orono, ME	PhD	AL/AO	01/01/93	12/31/93	$20000.00 $1472.00
Hall , Ian Materials Science University of Delaware, Newark, DE	PhD	WL/ML	01/01/93	12/31/93	$20000.00 $9580.00
Hedman , Paul Chemical Engineering Brigham Young University, Provo, UT	PhD	WL/PO	01/01/93	12/31/93	$19999.00 $7755.00
Henry , Robert Electrical & Computer Engineering University of Southwestern Louisiana, Lafayette, LA	PhD	RL/C3	12/01/92	05/31/93	$19883.00 $11404.00
Henson , James Electrical Engineering University of Nevada, Reno, NV	PhD	PL/WS	01/01/93	12/31/93	$19913.00 $9338.00

1993 SREP SUB-CONTRACT DATA

Report Author Author's University	Author's Degree	Sponsoring Lab	Performance Period	Contract Amount Univ. Cost Share
Hoe , Benjamin Electrical Engineering Polytechnic University, Brooklyn, NY	M.S.	RL/C3	09/01/92 05/31/93	$19988.00 $7150.00
Hughes , Rod Psychology Bowling Green State University, Bowling Green, OH	M.S.	AL/CF	01/01/93 04/15/94	$20000.00 $20846.00
Hui , David Mechanical Engineering University of New Orleans, New Orleans, LA	PhD	WL/FI	01/01/93 12/31/93	$20000.00 $0.00
Humi , Mayer Mathematics Worcester Polytechnic Institut, Worcester, MA	PhD	PL/LI	01/01/93 12/31/93	$20000.00 $5000.00
Innocenti , Mario Aerospace Engineering Auburn University, Auburn, AL	PhD	WL/MN	01/01/93 02/28/94	$20000.00 $12536.00
Jean , Jack Computer Science & Engineering Wright State University, Dayton, OH	PhD	WL/AA	01/01/93 12/31/93	$20000.00 $34036.00
Jouny , Ismail Electrical Engineering Lafayette College, Easton, PA	PhD	WL/AA	01/01/93 12/31/93	$19381.00 $4500.00
Kaikhah , Khosrow Computer Science Southwest Texas State College, San Marcos, TX	PhD	RL/IR	01/01/93 12/31/93	$20000.00 $0.00
Kaw , Autar Mechanical Engineering University of South Florida, Tampa, FL	PhD	WL/ML	01/01/93 12/31/93	$20000.00 $22556.00
Kheyfets , Arkady Mathematics North Carolina State University, Raleigh, NC	PhD	PL/LI	01/01/93 12/31/93	$20000.00 $2500.00
Kitchart , Mark Mechanical Engineering North Carolina A & T State University, Greensboro, NC	M.S.	AL/EQ	01/01/93 12/31/93	$20000.00 $0.00
Koblasz , Arthur Civil Engineering Georgia Institute of Technology, Atlanta, GA	PhD	AL/AO	01/01/93 12/31/93	$19826.00 $0.00
Koivo , A. Electrical Engineering Purdue University, West Lafayette, IN	PhD	AL/CF	01/01/93 06/30/94	$20000.00 $0.00
Kundich , Robert Biomedical Engineering University of Tennessee, Memphis, TN	PhD	AL/CF	01/01/93 12/31/94	$20000.00 $23045.00
Kuo , Spencer Electrical Engineering Polytechnic University, Farmingdale, NY	PhD	PL/GP	01/01/93 04/30/94	$20000.00 $9731.00

1993 SREP SUB-CONTRACT DATA

Report Author Author's University	Author's Degree	Sponsoring Lab	Performance Period		Contract Amount Univ. Cost Share
Liou , Juin Electrical and Computer Engineering Universtiy of Central Florida, Orlando, FL	PhD	WL/EL	01/01/93	12/31/93	$20000.00 $9073.00
Liou , Shy-Shenq Engineering San Francisco State Univesity, San Francisco, CA	PhD	WL/PO	01/01/93	12/31/93	$20000.00 $13387.00
Manoranjan , Valipuram Pure and Applied Mathematics Washington State University, Pullman, WA	PhD	AL/EQ	01/01/93	12/31/93	$19956.00 $10041.00
Marks , Dallas Electrical and Computer Engineering University of Cincinnati M.L., Cincinnati, OH	M.S.	WL/AA	10/01/92	06/30/93	$20000.00 $4731.00
Monsay , Evelyn Physics Le Moyne College, Syracuse, NY	PhD	RL/OC	01/01/93	12/31/93	$19634.00 $1510.00
Moor , William Industrial & Management Engineering Arizona State University, Tempe, AZ	PhD	AL/HR	01/01/93	12/31/93	$20000.00 $4833.00
Moore , Carlyle Physics Morehouse College, Atlanta, GA	PhD	AEDC/	01/01/93	12/31/93	$20000.00 $4880.00
Mulligan , B. Psychology University of Georgia Research, Athens, GA	PhD	AL/OE	01/01/93	04/15/94	$19998.00 $13936.00
Murphy , Richard Physics University of Missouri, Kansas City, MO	PhD	PL/WS	01/01/93	12/31/93	$20000.00 $13022.00
Nilan , Michael Information Studies Syracuse University, Syracuse, NY	PhD	RL/C3	01/01/93	12/31/93	$19998.00 $13016.00
Parrish , Allen Computer Science University of Alabama, Tuscaloosa, AL	PhD	RL/C3	01/01/93	12/31/93	$19919.00 $20599.00
Piersma , Bernard Chemistry Houghton College, Houghton, NY	PhD	FJSRL/	01/01/93	12/31/93	$20000.00 $4000.00
Potasek , Mary Applied Physics Columbia University, New York, NY	PhD	WL/ML	12/01/93	11/30/93	$20000.00 $7806.00
Qazi , Salahuddin Optical Communications SUNY/Institute of Technology, Utica, NY	PhD	RL/OC	01/01/93	12/31/93	$20000.00 $68000.00
Reardon , Kenneth Agricultural and Chemical Engineering Colorado State University, Fort Collins, CO	PhD	AL/EQ	01/01/93	01/31/94	$19996.00 $12561.00

1993 SREP SUB-CONTRACT DATA

Report Author Author's University	Author's Degree	Sponsoring Lab	Performance Period	Contract Amount Univ. Cost Share
Reynolds , David Biomedical & Human Factors Wright State University, Dayton, OH	PhD	AL/CF	01/01/93 06/30/94	$20000.00 $14063.00
Robinson , Donald Chemistry Xavier University of Louisiana, New Orleans, LA	PhD	AL/OE	01/01/93 06/30/94	$20000.00 $12935.00
Rodriguez , Armando Electrical Engineering Arizona State University, Tempe, AZ	PhD	WL/MN	01/01/93 12/31/93	$20000.00 $0.00
Roe , Larry Mechanical Engineering Virginia Polytechnic Inst & State Coll., Blacksburg, VA	PhD	WL/PO	01/01/93 12/31/93	$20000.00 $11421.00
Romeu , Jorge Assistant Prof. of Mathematics SUNY College at Cortland, Cortland, NY	PhD	RL/OC	01/01/93 12/31/93	$19997.00 $7129.00
Roppel , Thaddeus Electrical Engineering Auburn University, Auburn, AL	PhD	WL/MN	01/01/93 12/31/93	$20000.00 $21133.00
Roznowski , Mary Psychology Ohio State University, Columbus, OH	PhD	AL/HR	01/01/93 03/31/94	$19953.00 $6086.00
Rudzinski , Walter Chemistry Southwest Texas State University, San Marcos, TX	PhD	AL/OE	01/01/93 12/31/93	$20000.00 $10120.00
Sargent , Robert Engineering and Computer Science Syracuse University, Syracuse, NY	PhD	RL/XP	01/01/93 12/31/93	$20000.00 $11931.00
Schonberg , William Civil and Environmental Engineering University of Alabama, Huntsville, AL	PhD	WL/MN	01/01/93 12/31/93	$19991.00 $5083.00
Shaw , Arnab Electrical Engineering Wright State University, Dayton, OH	PhD	WL/AA	01/01/93 12/31/93	$20000.00 $4766.00
Shively , Jon Engineering & Computer Science California State University, Northridge, CA	PhD	PL/VT	01/01/93 12/31/93	$20000.00 $9782.00
Slater , Robert Mechanical & Industrial Engineering University of Cincinnati, Cincinnati, OH	M.S.	WL/FI	01/01/93 12/31/93	$20000.00 $8257.00
Stenzel , Johanna Arts & Sciences University of Houston, Victoria, TX	PhD	PL/LI	01/01/93 12/31/93	$20000.00 $9056.00
Tan , Arjun Physics Alabama A & M University, Normal, AL	PhD	PL/WS	01/01/93 12/31/93	$20000.00 $1000.00

1993 SREP SUB-CONTRACT DATA

Report Author Author's University	Author's Degree	Sponsoring Lab	Performance Period		Contract Amount Univ. Cost Share
Tetrick , Lois Industrial Relations Prog Wayne State University, Detroit, MI	PhD	AL/HR	01/01/93	12/31/93	$20000.00 $17872.00
Tew , Jeffery Industrial & Systems Engineering Virginia Polytechnic Institute, Blacksburg, VA	PhD	RL/IR	05/31/93	12/31/93	$16489.00 $4546.00
Tribikram , Kundu Civil Engineering and Engineering Universtiy of Arizona, Tucson, AZ	PhD	WL/ML	01/01/93	12/31/93	$20000.00 $9685.00
Tuthill , Theresa Electrical Engineering University of Dayton, Dayton, OH	PhD	WL/ML	01/01/93	12/31/93	$20000.00 $24002.00
Venkatasubraman , Ramasubrama Electrical and Computer Engineering University of Nevada, Las Vegas, NV	PhD	WL/ML	01/01/93	12/31/93	$20000.00 $18776.00
Wang , Xingwu Electrical Engineering Alfred University, Alfred, NY	PhD	AL/EQ	01/01/93	12/31/93	$20000.00 $10000.00
Whitefield , Philip Physics University of Missouri, Rolla, MO	PhD	PL/LI	01/01/93	03/01/94	$20000.00 $11040.00
Wightman , Colin Electrical Engineering New Mexico Institute of Mining, Socorro, NM	PhD	RL/IR	01/01/93	12/31/93	$20000.00 $1850.00
Womack , Michael Natural Science and Mathematics Macon College, Macon, GA	PhD	AL/OE	01/01/93	06/30/94	$19028.00 $6066.00
Yuvarajan , Subbaraya Electrical Engineering North Dakota State University, Fargo, ND	PhD	WL/PO	01/01/93	12/31/93	$19985.00 $22974.00

APPENDIX 1:

SAMPLE SREP SUBCONTRACT

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
1993 SUMMER RESEARCH EXTENSION PROGRAM SUBCONTRACT 93-133

BETWEEN

Research & Development Laboratories
5800 Uplander Way
Culver City, CA 90230-6608

AND

San Francisco State University
University Comptroller
San Francisco, CA 94132

REFERENCE: Summer Research Extension Program Proposal 93-133
Start Date: 01/01/93 End Date: 12/31/93
Proposal Amount: $20,000.00

(1) PRINCIPAL INVESTIGATOR: Dr. Shy Shenq P. Liou
Engineering
San Francisco State University
San Francisco, CA 94132

(2) UNITED STATES AFOSR CONTRACT NUMBER: F49620-90-C-09076

(3) CATALOG OF FEDERAL DOMESTIC ASSISTANCE NUMBER (CFDA): 12.800
PROJECT TITLE: AIR FORCE DEFENSE RESEARCH SOURCES PROGRAM

(4) ATTACHMENTS 1 AND 2: SREP REPORT INSTRUCTIONS

*** SIGN SREP SUBCONTRACT AND RETURN TO RDL***

1. BACKGROUND: Research & Development Laboratories (RDL) is under contract (F49620-90-C-0076) to the United States Air Force to administer the Summer Research Programs (SRP), sponsored by the Air Force Office of Scientific Research (AFOSR), Bolling Air Force Base, D.C. Under the SRP, a selected number of college faculty members and graduate students spend part of the summer conducting research in Air Force laboratories. After completion of the summer tour participants may submit, through their home institutions, proposals for follow-on research. The follow-on research is known as the Summer Research Extension Program (SREP). Approximately 75 SREP proposals annually will be selected by the Air Force for funding of up to $20,000; shared funding by the academic institution is encouraged. SREP efforts selected for funding are administered by RDL through subcontracts with the institutions. This subcontract represents such an agreement between RDL and the institution designated in Section 5 below.

2. RDL PAYMENTS: RDL will provide the following payments to SREP institutions:

- 90 percent of the negotiated SREP dollar amount at the start of the SREP Research period.
- the remainder of the funds within 30 days after receipt at RDL of the acceptable written final report for the SREP research.

3. INSTITUTION'S RESPONSIBILITIES: As a subcontractor to RDL, the institution

designated on the title page will:

a. Assure that the research performed and the resources utilized adhere to those defined in the SREP proposal.
b. Provide the level and amounts of institutional support specified in the RIP proposal.
c. Notify RDL as soon as possible, but not later than 30 days, of any changes in 3a or 3b above, or any change to the assignment or amount of participation of the Principal Investigator designated on the title page.

d. Assure that the research is completed and the final report is delivered to RDL not later than twelve months from the effective date of this subcontract, but no later than December 31, 1993. The effective date of the subcontract is one week after the date that the institution's contracting representative signs this subcontract, but no later than January 15, 1993.

e. Assure that the final report is submitted in accordance with Attachment 1.

f. Agree that any release of information relating to this subcontract (news releases, articles, manuscripts, brochures, advertisements, still and motion pictures, speeches, trade association meetings, symposia, etc.) will include a statement that the project or effort depicted was or is sponsored by: Air Force Office of Scientific Research, Bolling AFB, D.C.

g. Notify RDL of inventions or patents claimed as the result of this research as specified in Attachment 1.

h. RDL is required by the prime contract to flow down patent rights and technical data requirements in this subcontract. Attachment 2 to this subcontract contains a list of contract clauses incorporated by reference in the prime contract.

4. All notices to RDL shall be addressed to:

RDL Summer Research Program Office
5800 Uplander Way
Culver City, CA 90230-6608

5. By their signatures below, the parties agree to the provisions of this subcontract.

A. S. Sopher
____
Abe S. Sopher
RDL Contracts Manager

____
Signature of Institution Contracting Official

____
Typed/Printed Name

____
Date

____
Title

____
Institution

_______________________(Date/Phone)

ATTACHMENT 2
CONTRACT CLAUSES

This contract incorporates by reference the following clauses of the Federal Acquisition Regulations (FAR), with the same force and effect as if they were given in full text. Upon request, the Contracting Officer or RDL will make their full text available (FAR 52.252-2).

FAR CLAUSES	TITLE AND DATE
52.202-1	DEFINITIONS (SEP 1991)
52.203-1	OFFICIALS NOT TO BENEFIT (APR 1984)
52.203-3	GRATUITIES (APR 1984)
52.203-5	COVENANT AGAINST CONTINGENT FEES (APR 1984)
52.304-6	RESTRICTIONS ON SUBCONTRACTOR SALES TO THE GOVERNMENT (JUL 1985)
52.203-7	ANTI-KICKBACK PROCEDURES (OCT 1988)
52.203-12	LIMITATION ON PAYMENTS TO INFLUENCE CERTAIN FEDERAL TRANSACTIONS (JAN 1990)
52.204-2	SECURITY REQUIREMENTS (APR 1984)
52.209-6	PROTECTING THE GOVERNMENT'S INTEREST WHEN SUBCONTRACTING WITH CONTRACTORS DEBARRED, SUSPENDED, OR PROPOSED FOR DEBARMENT (NOV 1992)
52.212-8	DEFENSE PRIORITY AND ALLOCATION REQUIREMENTS (SEP 1990)
52.215-1	EXAMINATION OF RECORDS BY COMPTROLLER GENERAL (APR 1984)
52.215-2	AUDIT - NEGOTIATION (DEC 1989)
52.222-26	EQUAL OPPORTUNITY (APR 1984)
52.222-28	EQUAL OPPORTUNITY PREAWARD CLEARANCE OF SUBCONTRACTS (APR 1984)

52.222-35	AFFIRMATIVE ACTION FOR SPECIAL DISABLED AND VIETNAM ERA VETERANS (APR 1984)
52.222-36	AFFIRMATIVE ACTION FOR HANDICAPPED WORKERS (APR 1984)
52.222-37	EMPLOYMENT REPORTS ON SPECIAL DISABLED VETERAN AND VETERANS OF THE VIETNAM ERA (JAN 1988)
52.223-2	CLEAN AIR AND WATER (APR 1984)
52.232-6	DRUG-FREE WORKPLACE (JUL 1990)
52.224-1	PRIVACY ACT NOTIFICATION (APR 1984)
52.224-2	PRIVACY ACT (APR 1984)
52.225-13	RESTRICTIONS ON CONTRACTING WITH SANCTIONED PERSONS (MAY 1989)
52.227-1	AUTHORIZATION AND CONSENT (APR 1984)
52.227-2	NOTICE AND ASSISTANCE REGARDING PATENT AND COPYRIGHT INFRINGEMENT (APR 1984)
52.227-10	FILING OF PATENT APPLICATIONS - CLASSIFIED SUBJECT MATTER (APR 1984)
52.227-11	PATENT RIGHTS - RETENTION BY THE CONTRACTOR (SHORT FORM) (JUN 1989)
52.228-6	INSURANCE - IMMUNITY FROM TORT LIABILITY (APR 1984)
52.228-7	INSURANCE - LIABILITY TO THIRD PERSONS (APR 1984)
52.230-5	DISCLOSURE AND CONSISTENCY OF COST ACCOUNTING PRACTICES (AUG 1992)
52.232-23	ASSIGNMENT OF CLAIMS (JAN 1986)
52.237-3	CONTINUITY OF SERVICES (JAN 1991)

52.246-25	LIMITATION OF LIABILITY - SERVICES (APR 1984)
52.249-6	TERMINATION (COST-REIMBURSEMENT) (MAY 1986)
52.249-14	EXCUSABLE DELAYS (APR 1984)
52.251-1	GOVERNMENT SUPPLY SOURCES (APR 1984)

APPENDIX 2:

SAMPLE TECHNICAL EVALUATION FORM

1993 SUMMER RESEARCH EXTENSION PROGRAM

RIP NO.: 93-0092
RIP ASSOCIATE: Dr. Gary T. Chapman

Provided are several evaluation statements followed by ratings of (1) through (5). A rating of (1) is the lowest and (5) is the highest. Circle the rating level number you best feel rates the statement. Document additional comments on the back of this evaluation form.

Mail or fax the completed form to :

RDL
Attn: 1993 SREP TECH EVALS
5800 Uplander Way
Culver City, CA 90230-6608
(FAX: 310 216-5940)

1.	This SREP report has a high level of technical merit.	1	2	3	4	5
2.	The SREP program is important to accomplishing the labs's mission	1	2	3	4	5
3.	This SREP report accomplished what the associate's proposal promised.	1	2	3	4	5
4.	This SREP report addresses area(s) important to the USAF	1	2	3	4	5
5.	The USAF should continue to pursue the research in this SREP report	1	2	3	4	5
6.	The USAF should maintain research relationships with this SREP associate	1	2	3	4	5
7.	The money spent on this SREP effort was well worth it	1	2	3	4	5
8.	This SREP report is well organized and well written	1	2	3	4	5
9.	I'll be eager to be a focal point for summer and SREP associates in the future.	1	2	3	4	5
10.	The one-year period for complete SREP research is about right	1	2	3	4	5

******USE THE BACK OF THIS FORM FOR ADDITIONAL COMMENTS******

LAB FOCAL POINT'S NAME (PRINT): ______________________

OFFICE SYMBOL: ______________ PHONE: ______________

CHARACTERIZING THE CARDIOVASCULAR SYSTEM IN NEONATES: APPLICABILITY TO HIGH PERFORMANCE AIRCRAFT AVIATORS

Robert Craig Kundich, M.A.
Research Assistant
Department of Biomedical Engineering

Jack W. Buchanan, MSEE, MD
Associate Professor
Departments of Biomedical Engineering,
Medicine, and Physiology

Henrietta S. Bada, M.D.
Departments of Pediatrics, Obstetrics,
and Gynecology

University of Tennessee, Memphis
899 Madison Ave., Suite 801
Memphis, TN 38163

Final Report for:
Research Initiation Program
Armstrong Laboratory

Sponsored by:
Air Force Office of Scientific Research
Bolling Air Force Base, Washington, D.C.

and

University of Tennessee, Memphis

April, 1994

CHARACTERIZING THE CARDIOVASCULAR SYSTEM IN NEONATES: APPLICABILITY TO HIGH PERFORMANCE AIRCRAFT AVIATORS

Robert Craig Kundich, M.A.
Research Assistant
Department of Biomedical Engineering
University of Tennessee, Memphis

Abstract

The capabilities of high performance tactical aircraft (HPA) have dramatically increased in the past 50 years. Life Support Systems for the next generation of HPA have been requested to provide G-LOC protection to +12 Gz with an elevated onset rate (Naval Air Warfare Center). Such a protection scheme will require innovative enhancements of existing G-LOC protection schemes. The need for ventricular assistance devices, such as cardiac pacemakers and external counterpulsation are obvious in a medical setting. However, in HPA, ATAGS and Combat EDGE are ventricular assist devices for a healthy heart in a conditioned individual.

If the view of all subjects being pathological at +12 Gz is considered, then the objective is to diagnose and intervene in the pathological crisis. The use of biological sensors and triggers have not been integrated extensively in the current sustained G-LOC protection scheme. However, to provide optimal, individualized cardiac pacing and vascular impedance during elevated +Gz, a new generation of "smart" life support systems is necessary.

The objective of this research is to build on work conducted at Armstrong Laboratory under the direction of Larry Krock, by applying biological signal processing schemes to the premature newborn infant. The major objective is to in the future enhance physician diagnostic capability in the prediction of cardiovascular phenomena, and cerebral phenomena such as intraventricular hemorrhage. This predictive ability will hopefully have carryover into the assessment of aviators and the design of advanced life support systems.

CHARACTERIZING THE CARDIOVASCULAR SYSTEM IN NEONATES: APPLICABILITY TO HIGH PERFORMANCE AIRCRAFT AVIATORS

Robert Craig Kundich, M.A.

INTRODUCTION

The capabilities of high performance tactical aircraft (HPA) have dramatically increased in the past 50 years. Life Support Systems for the next generation of HPA have been requested to provide G-LOC protection to +12 Gz with an elevated onset (Naval Air Warfare Center). Such a protection scheme will require innovative enhancements of existing G-LOC protection schemes. The need for ventricular assistance devices, such as cardiac pacemakers and external counterpulsation are obvious in a medical setting. However, in HPA, ATAGS and Combat EDGE are ventricular assist devices for a healthy heart in a conditioned individual.

If the view of all subjects being pathological at +12 Gz is considered, then the objective is to diagnose and intervene in the pathological crisis. The use of biological sensors and triggers have not been integrated extensively in the current sustained G-LOC protection scheme. However, to provide optimal, individualized cardiac pacing and vascular impedance during elevated +Gz, a new generation of "smart" life support systems is necessary.

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Objective 1: To develop an efficient and accurate approach to the detection of biological signals and analysis in the time domain in real time.
Objective 2: To develop an efficient algorithm for frequency domain analysis of biological signals in real time.
Objective 3: To apply the approaches in objectives 1 and 2 to the transient response to tilt in the premature infant.

BACKGROUND AND SIGNIFICANCE

The effective and efficient management of biological diversity is essential for military success. Programs already exist in the military towards selecting individuals with desirable characteristics for certain missions. Within each branch of the military there are elite fighting units such as the Green Berets, Navy SEALS, Army Rangers, and the Delta Force. Each fighting unit has set out certain criteria for the selection of its military personnel through minimizing biological diversity. Although the modeling of other elite military personnel can answer some unique physiological questions, we have focused on the unique physiological requirements of USAF high performance aircraft (HPA) aviators. The tendency towards the restriction of biological diversity in aviators is an attempt by the United States Air Force to create a rational process for selecting individuals with the highest potential for battlefield success. A major objective is to use Darwinian selection advantageously, by first understanding the human and machine performance characteristics that lead to battlefield success and then institute a pilot prescreening and training program to enhance those characteristics essential for battlefield success. This approach coupled with the development of advanced aircraft and life support systems provides an opportunity for achieving both a biological and technological advantage over adversaries. With continual improvements in aircraft, life support, and physiological assessment tools, performance criteria can be continually refined along with enhancing prescreening programs and countermeasures.

Two areas have emerged as areas where improvements may enhance aviator survivability and performance; enhanced prescreening of aviator cardiovascular performance and the development of "smart systems" for biological countermeasures. These systems may include the deployment of biological sensing devices along with advanced life support systems such as Combat EDGE and ATAGS. Currently, the proposed specifications for the next generation of G-LOC protection is +12 Gz with an elevated onset rate. This will require innovative deviations from the conventional approaches.

The modern aviator must evade or seek out and engage his adversary while at the same time striving to maintain cognitive and visual awareness. However, the task of enemy engagement or evasion decreases the ability to maintain cognitive and visual awareness. An aircraft may fly at very high speeds through six degrees of freedom (3 linear and 3 rotational), while to a more limited degree the aviator can

also move around in six degrees of freedom. Gravity, flight, and aviator movements results in acceleration being placed on the aviator. A common nomenclature is necessary when discussing the magnitude and direction of the acceleration (Table 1). The measure of G as a unitless multiplier of gravitational acceleration (9.81 m/sec^2) is used to describe the relative intensity of the acceleration. Of major concern to aviators is +Gz acceleration.

Table 1. Physiological Nomenclature for G force

Inertial Resultant of Body Acceleration

Linear Acceleration	Physiological Response
Forward +Gx	Transverse A-P G Supine G Chest to back
Backward -Gx	Transverse P-A G Prone G Back to chest G
Headward +Gz	Positive G Toward feet
Footward -Gz	Negative G Toward head
To Left +Gy	Right lateral G
To right -Gy	Left lateral G

From: Burton RR, Meeker LJ, Raddin JH. Centrifuges for studying the effects of sustained acceleration on human physiology. IEEE, 1991; 56-65

Elevated +Gz acceleration leads to pooling of blood in the vasculature of the legs and reduction of blood flow to the cerebral and visual regions. Maximum levels of +Gz of selected worldwide aircraft are presented in Table 2. Paradoxically, perfusion to the cerebral region is minimized during enemy engagement and evasion where high +Gz is encountered. Thus, a perfusion paradox can be stated:

Perfusion Paradox: During times of elevated cognitive and physiological stress cerebral and ocular perfusion are minimized.

Table 2: + Gz Capabilities of Selected Fighter Aircraft

Country	Manufacturer	Aircraft	+/-Gz
France	Dassault	Mirage 2000	+9
Yugoslavia	Soko	G-4 Super Galeb	+8/-4.2
USA	Northrop	F-20 Tigershark	+9
USA	McDonnell-Douglas	F-15 Eagle	+9/-3
USA	Lockeed	F-22	+9
USA	Lockeed	F-117A	+6
USA	General Dynamics	F-16	+9
USA	Bell Helicopter	AH-1(4B)W Viper	+3.39
UK	British Air	BAe Hawk T-45A Goshawk	+8/-4
UK	British Air	Harrier	+7.8/-4.2
USSR	Mikoyan	Mig 29 Fulcrum	+9.5
USSR	Mikoyan	Mig 25 Foxbat	+5
USSR	Mikoyan	Mig 27 Floger	+7
Swiss	JAS	39 Gripen (Griffen)	+9
Poland	IL	Iridium	+8/-4
Israel	IAI	Lavi (Young Lion)	+7.2
Israel	IAI	Kfir (Lion Cub)	+7.5
Israel	IAI	Nammer (Tiger)	+9
International	Eurofighter	EFA	+9/-3
International	Dassault/Dornier	Alpha Jet	+12/-6.4
International	Panavia	Tornado IDS	+7.5
International	Rockwell/MBB	X-31A EFM	+9/-4
Czechoslavakia	Aero	Albatross	+8/-4
China	CAC	Mikoyan J-7	+8.5

Data extracted from Janes World Aircraft 1993.

Such perfusion minimization has led to a series of crashes and fatalities in high performance aircraft. Ten crashes of high performance aircraft occurred in one four year period due to G induced loss of consciousness (G-LOC). There is a Gaussian distribution of tolerance to elevated +Gz, suggesting that some individuals are better equipped to handle the elevated +Gz. However, there is a subset of the aviator population that will have below normal tolerance to +Gz. The common feature among the high tolerance and low tolerance groups is their effort to resolve the reduction in cerebral and ocular perfusion due to elevated +Gz. Therefore, it would be appropriate to attempt to predict an individuals +Gz tolerance and determine the temporal organization of physiological responses in high +Gz tolerance and low +Gz tolerance groups.

The successful resolution of +Gz tolerance prediction can only be achieved after a more complete understanding of the organized physiological response to high +Gz is developed. The physiological response to high +Gz encompasses many systems including renal, cardiovascular, and respiratory systems.

It is their integrated response over time which determines the tolerance to +Gz. Two points of view may be interpreted when considering the response to + Gz; homeostasis and LeChateliers principle.

Cannon's homeostasis suggests a constancy of the internal environment. Yet, homeostasis is a matter of perspective. It is obvious that maintaining oxygen delivery to the brain is important. Yet to maintain this many other systems are altered along the production-delivery-consumption complex. For instance, the lungs may increase frequency and depth of breathing and the heart may beat faster. Thus, the constant environments of these two are altered.

Thus, the understanding of physiological response to +Gz can not be discussed in terms of homeostasis alone. Therefore LeChateliers principle is important. LeChateliers states that a system in equilibrium will adjust to minimize the effect of an applied force. This gives a unique perspective when considering the response to +Gz. We can view the systemic physiological responses in an n- dimensional state space. A certain trajectory will be traced in this space over time while the system is in equilibrium. When perfusion is altered, there needs to be a compensation. Thus, the organism searches for the best new solution to maintain a new equilibrium with the altered variables. If it is assumed that the system is ordered and not random, then it can tentatively be concluded that some individuals with high +Gz tolerance employ a better search algorithm or that the search can be artificially manipulated.

Therefore, it is evident that two types of modeling are necessary. In one case, we are trying to rapidly and in real time predict the physiological responses to a G challenge. On the other hand we are trying to prescreen for quality pilots. Although the objectives appear on the surface to be different, commonalties exist including the involvement of the autonomic nervous system. In assessing the cardiovascular control loops, it is possible to use preexisting noninvasive clinical tests of autonomic function. These tests in many laboratories have been computerized to aid in the efficient gathering of results, but provide little in the way of garnering new information.

The autonomic tests are often used to evaluate physiological responses to transient interventions. Yet, clinically often only maximum and minimum responses are recorded with little emphasis on the time response or the relationship of the physiological variables following the transient interventions. Therefore, a recent paper has disputed the value of ANS testing in predicting G tolerance.

Conventional ANS testing has been described extensively elsewhere including 3 papers by our group submitted to the SRP and will not be repeated in extensive detail here.

NEONATAL CARDIOVASCULAR ASSESSMENT

Neonatal cardiovascular assessment, in contrast to adult assessment may hold greater similarities to the aviator workplace. A primary objective is to enhance the decision making capabilities of the physician by providing faster access to more accurate information. This would be analogous to enhancing information speed and complexity to life support systems to optimize their performance. Additionally, in the neonate minimal invasiveness is a prime consideration that is similar to the aviator. Both performance sites (Intensive Care and the Cockpit) are noisy environments with constant subject movements and simultaneous execution of multiple activities. Thus, biological signal processing is more complicated in both environments compared to evaluating an adult in a laboratory. Techniques developed in the difficult intensive care unit may therefore be easier to transfer into a cockpit environment.

PRELIMINARY STUDIES

Armstrong Laboratory, Brooks AFB

During the summer of 1992 and 1993, the primary investigator has spent time at Brooks AFB working with Dr. Larry Krock. We have developed packages on the Macintosh to analyze biological signals (specifically BP and ECG) in both the time domain and frequency domain.

UT-Memphis

At the medical center we have been involved in a variety of projects to gain a greater understanding of cardiovascular function in control subjects, diabetics, and transplant patients. This has included the Holter monitoring of Cardiac transplant recipients, and the autonomic function testing of diabetic subjects.

EXPERIMENTAL DESIGN AND METHODS

Protocol

Seven premature infants (< 3 days old) in the Neonatal Intensive Care Unit at the Regional Medical Center, Memphis, TN participated in the data acquisition portion of this protocol. Four data

acquisition periods of 10 minutes duration were serially conducted on each patient. Two periods of supine rest were followed by a 35 degree tilt for 10 minutes and a ten minute supine rest.

Hardware

Each of the 40 patient beds in the Neonatal Intensive Care Unit at the Regional Medical Center are equipped with the Hewlett Packard Component Monitoring System (HP CMS). This system integrates data collection for BP, respiration, ECG, and various other measurements into one computer based package. Using a message based system, data and commands can be passed between the various modules and processing units. A feature of this system is a 38,400 baud bi-directional serial port. Using software provided by Hewlett Packard, it is possible to collect data from the HP CMS and display it on a laptop computer. We modified the software to provide to include real time buffered storing of the continuous ECG (at 512 Hz) and second by second updated Blood Pressure, Heart Rate, respiration, and oxygen saturation values. Future modifications will enhance the package to additionally include real time acquisition for blood pressure or respiration, along with transcutaneous oxygen and carbon dioxide values.

Acquisition and Analysis Methods

Analog Prefilters

The purpose of prefiltering the analog signals in biological variability analysis is to avoid the introduction of errors due to aliasing. The ideal prefilter for heart rate variability studies should have minimal attenuation in the frequencies of interest (passband, 0 to 125 Hz, pediatric 0 to 150 Hz) (1), and create a large signal attenuation at higher frequencies. The cutoff and stopband are two critical frequencies in the design of a prefilter. The cutoff frequency (Fc) is the point where signal attenuation is initiated (an attenuation of -3 dB). The stopband frequency (Fs) is where attenuation is typically greater than -70 dB. The ratio of stopband frequency to cutoff frequency is often calculated to give a measurement of the rolloff from passband to stopband In a lowpass filter, the passband region is before the cutoff frequency. In the passband region, minimization of ripples is important.

There are currently four popular types of analog filters; Butterworth, Chebyshev, Elliptic, and Bessel. The Butterworth offers a maximally flat passband, while the Chebyshev has the steepest transition from passband to stopband. The Bessel filter has a maximally flat time delay. The Butterworth filter

trades off everything else for maximal flatness. However, the Butterworth has less than ideal phase characteristics. If 1 dB ripples in the passband are acceptable, then a Chebyshev filter can be used. It allows greater sharpness at the knee (3 dB), but has less than ideal phase characteristics. However, no matter what design is employed, flatness of the passband is never really possible. Design criteria calls for very tight tolerances of the resistors and capacitors (1%), but some ripple still occurs. The elliptic or Cauer filter is a variation of the Chebyshev filter and is easy to implement with CAD. The elliptic filter is indicated where the shape of the waveform is important. When accuracy and signal quality are necessary and some delay in the resulting signal output is acceptable, filters with a linear phase response are desirable. If all channels sampled are filtered with the same type of linear phase filter, then all signals will be shifted equally in the time domain. Butterworth filters built by UT-Memphis Instrumentation Division are used at the medical center when an A/D board is used for data acquisition. While the laptop is linked to the HP CMS by serial interfacing, no prefiltering is necessary, as this is handled internally by the HP CMS and signal transfer is in a digital format.

Sampling Frequency

The sampling frequency is determined by multiplying the stopband of the prefilter by 2. This value is then multiplied by the number of channels to get the total sampling rate. Sampling at twice the stopband frequency allows for 1 bit resolution to be achieved if the stopband is at -72 dB. To simplify the calculation of storage space requirements, the sampling rate should also be a power of two.

Through the use of signal decimation techniques, it is possible to alter the sampling rate. For a signal sampled at 256 Hz and 1024 Hz, the errors for sampling a 100 BPM heart rate signal range from 2.34 to 0.59 msec, respectively. However, it is possible that both sampling rates may give the same information about the heart rate intervals. The only way to assess this is by doing a signal to noise analysis.

Pizzuti et al. did an analysis of sampling rate and ECG using a system with ± 9 bits accuracy (20). Sampling at 250 Hz rather than 500 Hz is acceptable for large interval measurements such as R-R interval (2). However, sampling at 125 Hz introduced significant errors in interval measurements (2). Merri et al. studied signal to noise ratios of R-R interval measurements at various sampling frequencies

(3). The highest quality signal was at 256 Hz, followed by sampling at 128 Hz and 64 Hz (3). Again, supporting the contention of sampling at greater than 250 Hz. It was suggested that the more variable the R-R intervals are, the greater the noise necessitating a higher sampling frequency.

To insure the integrity of the data analysis, it is appropriate to conduct a signal to noise test on each set of data. This will insure that no errors are introduced in the analysis through improper sampling rate selection. Initially we have chosen 1024 Hz as the sampling rate for each channel when acquiring signals via A/D, since the filters at the medical center are of a lower quality than commercially bought filters. While using the HP CMS as a data acquisition front end we are limited by the hardware to a maximum sampling rate of 512 Hz. For the data collected in this preliminary project, the sampling rate was selected to be 256 Hz.

ECG Noise Suppression

A byproduct of using the surface electrode for the collection of the ECG signal is noise and baseline wander. A new method using mathematical morphological operators for the suppression of noise in the ECG signal has recently appeared in the scientific literature (4). Mathematical morphology is a technique that has been used primarily in image processing and has been used by some Hollywood studios in the film making process. A example of mathematical morphology would be to take a digital representation of an apple and having it follow a transition path turn into an orange.

A detailed explanation of the mathematical morphology technique applied to the ECG signal is presented elsewhere, but will briefly be described here (4). The objective is to convert a signal containing random noise into a signal devoid of noise. To achieve this objective, mathematical operations referred to as opening and closing are performed on the original signal with a five point structuring element. Basically, the original ECG signal is parallel processed along two paths. One path consists of an opening function followed by a closing function. The other path is a closing function followed by an opening function. The two paths are then averaged, resulting in an ECG signal with reduced random noise content. In essence, signal valleys are filled in and signal peaks are cut off. For data gathered from the HP CMS it was determined that noise removal was not necessary.

ECG Baseline Wander Normalization

Once random noise is removed from the ECG signal, it would be appropriate to normalize the baseline wander in the signal. Baseline wander can have a negative influence on the QRS detection algorithms. Additionally, it may make interpretation of the ECG difficult. Two approaches have been considered for using software post-processing to remove baseline wander (4,5). The first method involves mathematical morphology which was described previously (4). However, in the removal of baseline wander a longer structuring element (41 elements) is used (4). Because of the recursive nature of the mathematical morphology algorithm, it may be possible to use the algorithm in real time processing (with a minor delay). The real time implementation of the Chu and Delp algorithm will be part of the next phase of software development for the Newborn Center.

The other software based approach is to remove baseline wander with a digital high pass filter (5). Using this filter design the data is first passed through the filter in the forward direction. The resulting array is then reversed and passed through the filter again, yielding the final array with a normalized baseline. Each filtering procedure causes a nonlinear phase shift in the data. However, because the filtering of each stage occurs in opposite directions the resultant phase shift is minimized, and is in fact close to zero (5).

Peak Detection Algorithms

Once an analog ECG signal has been pre-filtered and converted into digital form by sampling at an appropriate rate, the R peaks of each QRS complex must be detected. Over thirty seven different methodologies have been published concerning the detection of QRS peaks (6). One of the simplest approaches to use, if the ECG signal has a stable baseline, is a peak threshold detection of a negative derivative. When the derivative signal crosses the zero line (corresponding to a R peak) the peak detector records the time of occurrence. If the data is not free of noise or unstable this will not work accurately. For instance, the baseline wander may cross the zero or threshold line yielding a faulty detection. This method may also be corrupted by high T waves.

Friesen et al. present two approaches by others that appear to be very appropriate for the analysis of the ECG during centrifugation studies (6). The Menard method is a simple approach to QRS peak detection. The first derivative of the ECG voltage is computed by formula, and the maximum derivative

of the array is used to set a threshold to compare other values against for possible detections (6). The Okada method is mathematically more intensive as it requires numerous steps for a digital filtering approach. Therefore, the Menard QRS detection method was employed for this experiment.

Once the complexes are detected it is necessary to find the true peak. A simple approach would be to find the first point following the detection where the derivative is zero. However, with the noisy environment there may be may such points a short distance from the QRS detection. Thus, it is more appropriate to find the maximum value of the ECG signal within a short window following the QRS detection. Visual display and editing of the ECG detections will insure that proper placement of an ECG detect has occurred.

Instantaneous Heart Rate Determination

Although the heart rate power spectrum can be computed using just the R-R intervals, it tends to create errors in the spectrum. To obtain a more precise power spectrum representation, the heart rate needs to be sampled at regularly spaced intervals; in other words an instantaneous heart rate. Five methodological approaches exist for the determination of instantaneous heart rate (7,8). Factors to be considered include correcting for the delay encountered in some of the methods and the errors induced by each methodological approach. De Boar et al. present three methods; spectrum of intervals, spectrum of counts, and spectrum of inverse integrals (8). Berger et al. present two methods (7). The first method involves taking the reciprocal of the R-R interval duration and passing it through a low pass filter window with a width of 2 times the sampling frequency.

An equivalent approach to determine instantaneous rate is to let:

$R_i= f_r*n_i/2$ where R is the instantaneous rate, f_r is the sampling rate and n_i is the sum of all fractions of intervals covered by that window (7).

Computing the Power Spectrum

The power spectrum can be computed after the biological signal is in digital form and preferably converted to an instantaneous sampling rate. Nine methods have been described for the generation of power spectrums from time domain signals (9). One of these approaches has three variations, bringing the total to eleven possible methods with their own distinct advantages and drawbacks (9). The power

spectrum is an assessment of the relative contribution of each frequency to the signal. For instance, if a signal repeats at exactly a 2 Hz period and 3 Hz period, such as two superimposed sine waves, two sharp peaks will appear. However, if a signal is composed of repeating components of various periods of duration, multiple peaks are possible.

The generation of a power spectrum is typically based on two approaches; the autoregressive approach and the fast Fourier transform (FFT) based approaches. Press et al provide C algorithms for both approaches (10). The AR approach has the advantage over the FFT in that it does not require a power of two for the number of samples (9). Additionally, less samples are required (9). On the other hand, more care must be employed in the use of the AR approach. The proper order of the AR approach can be determined using the Akiake Information Criteria (AIC) (11). The easiest method is the FFT based, periodogram approach. Minimal computational and software design strain is necessary to generate the power spectrum. A variation on this theme is the Blackman-Tukey approach, employed by Cohen's group (7). A practical application of the AR approach is in Bartoli et al (12) and an additional algorithm in FORTRAN is in Marple (11).

Recently, additional approaches to frequency domain analysis have been proposed including complex demodulation and the use of a forgetting factor with the autoregressive approach. Complex demodulation is based on harmonic analysis and was used by Shin to study autonomic responses in dogs (13). This approach appears to show promise for the frequency domain analysis of ECG signals in aviators, this is due to what Shin refers to as the time-local characteristics of the complex demodulation process (13). The AR approach with forgetting factor, uses a geometric window that allows the more recent data to be considered to a greater degree than previous data in the power spectrum calculations. This allows for a more rapid response in the power spectrum to alterations in the underlying time domain signal. The AR approach with and without forgetting factor will be employed in this set of experiments.

Presentation of Power Spectrum Results

After the selection of a method for computing the power spectrum, the results must be presented in an understandable format. On a two dimensional graph of the power spectrum, the frequency is along the X axis. Conversely, the x-axis may also be in units of cycles/beat if the De Boar approach is followed.

This may also then be converted to equivalent Hertz by multiplying the x-axis values by the mean R-R interval. The values along the y-axis are unitless for normalized data and in units of $msec^2/Hz$ if not normalized. If the De Boar method is used the units are $msec^2$/cycles/beat. Normalization of the power spectrum occurs when the power spectrum values are divided by the mean of the interval squared. The next factor to consider is whether the amplitude or power spectrum is being plotted on the y axis. Amplitude is simply the square root of the power spectrum.

Once the various methodologies are sorted out, it is necessary to interpret the power spectrum density plots. Of considerable importance is if the subjects were under controlled breathing or free breathing. Controlled breathed at a regularly spaced interval will cause a large spectral peak at the frequency of breathing. Whereas free breathing causes a more diffuse peak. This points out the stunning influence of vagal innervation on heart rate.

Resolution of the spectral plot is very important. The maximum resolution is a function of T^{-1}, with T equaling the period. For 5 minutes the resolution would be 1/300 Hz or .0033 Hz. A longer period is necessary to generate smaller interval values. Thus, resolution is enhanced significantly as the period is increased.

RESULTS

The figures presented below are indicative of the results being obtained in the newborn infant. Preliminary data analysis has occurred. A more detailed presentation of the results will occur at the 1994 Biomedical Engineering Society Meeting in Tempe Arizona, as an extended abstract is being prepared for the 1994 BMES student paper competition. Power spectra using the methods described above will be computed for all subjects

Sample	Heart Rate	Syst. Press	Dias. Press	Mean Press	Pulse Press	Resp Rate
0	132	55	32	41	23	44
1	132	54	32	41	22	47
2	132	54	32	41	22	45
3	131	54	32	41	22	46
4	131	54	32	41	22	46
5	130	54	32	41	22	43
6	129	54	32	41	22	42
7	129	54	31	40	23	42
8	129	54	31	40	23	41
9	130	54	31	40	23	42
10	130	54	31	40	23	42

Figure 1. A representative example of the numerical data received during a data collection session

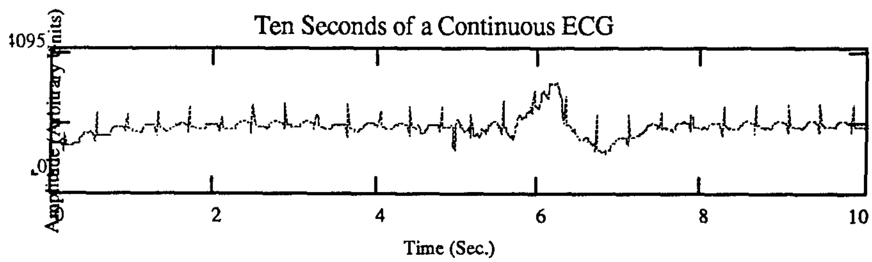
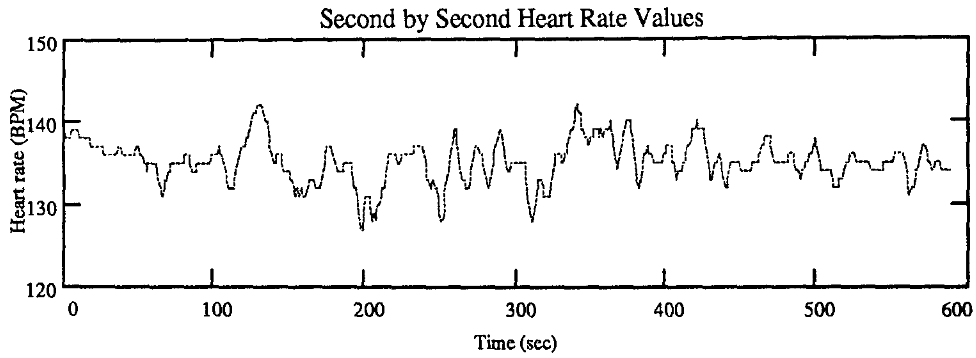


Figure 2. Replotting of the ECG waveform collected during this experiment.



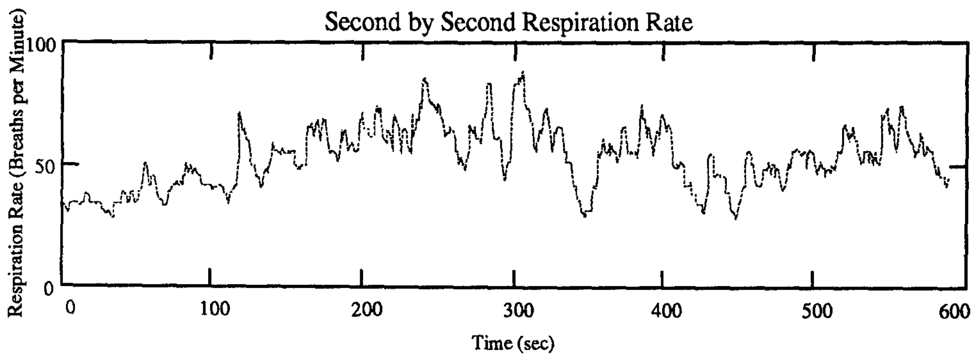


Figure 3. Time plots of HR and Respiration numerical data.

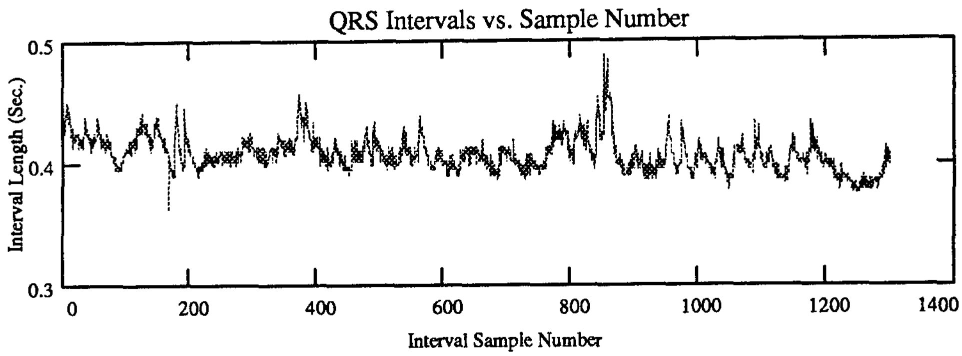


Figure 4. Interval between QRS complexes as detected using a threshold and derivative method and plotted over time

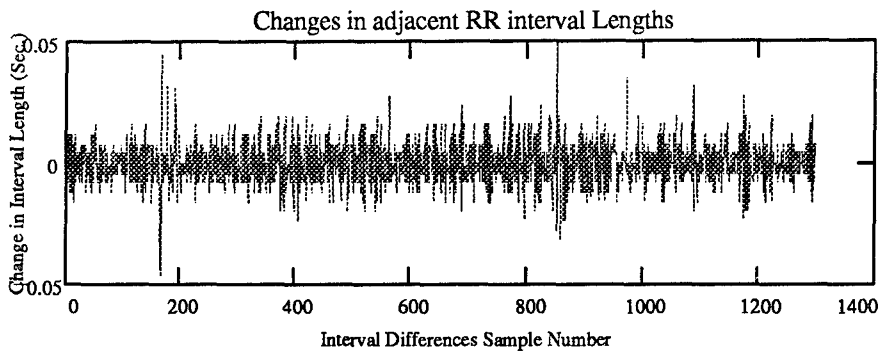


Figure 5. Differences in interval lengths for adjacent RR Intervals

CONCLUSIONS & FUTURE DIRECTIONS

The system and methodologies developed under this grant allow for a rapid (<2 minutes) initiation of data collection at a patients bedside. The portable nature of the data acquisition reduces interference with medical personnel and allows acquisition to occur at any bed, eliminating the need to reserve beds exclusively for a single research project.

Preliminary data from this study indicate that variability exists in the Neonate ECG. However, it has yet to be determined if the orthostatic stress used in this experiment was sufficient to alter the cardiovascular response of the neonate. To the authors knowledge, orthostatic tolerance in the newborn has not been studied extensively, and we did not wish to tilt the infants to a level common in adult tolerance tests (+60 to +70 degrees). It has been suggested that the premature infant has an immature autonomic system which develops in the days following birth. This situation may lend to a comparison in

a single individual of an autonomic system with varying levels of integrity. If tools can be developed to understand the ANS development progression in the neonate, it is reasonable to expect that such tools may possibly be used to evaluate the debilitation or insufficiency of the ANS in certain aerospace personnel.

Funding provided under this grant has aided substantially in the training of a young scientist and has served to provide the University of Tennessee with data being used in submission for a 4 year NIH Neonatal Brain Injury Grant (H. Bada, principal investigator). Further development is being done on the software and hardware. In the next year, cerebral blood flow experiments will be conducted, along with interfacing our computers with the Spacelab systems in intermediate care. This will double the number of patients (n=80) available on a daily basis that may be potentially enrolled in a research project.

As Robert Kundich progresses towards his Doctorate in Biomedical Engineering, he hopes to be able to provide USAF Armstrong Laboratory with a multiplatform signal analysis package geared towards aviator assessment.

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AN EMPIRICAL TEST OF A METHOD FOR COMPARISON OF ALTERNATIVE MULTISHIP AIRCRAFT SIMULATION SYSTEMS UTILIZING BENEFIT-COST EVALUATION

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ABSTRACT

This research tested, validated and refined procedures for completing the benefit-cost evaluation of aircraft simulation systems. This was accomplished through an evaluation and improvement of the overall benefits computation model. In addition, the cost model originally was completely updated and refined. Both of these models were implemented in spreadsheet formats so that they could be easily manipulated to portray different organizational configurations and alternative methods of implementing simulation systems. A spreadsheet was developed which links all benefit and cost results into a complete benefit-cost analysis. This provides a tool for management decision making and evaluation of simulator systems proposed for operational use in the Air Force.

AN EMPIRICAL TEST OF A METHOD FOR COMPARISON OF ALTERNATIVE MULTISHIP AIRCRAFT SIMULATION SYSTEMS UTILIZING BENEFIT-COST EVALUATION

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INTRODUCTION

The U. S. Air Force (USAF) desires, in so far as possible, that proposed capital expenditures be based on a benefit-cost comparison among all competing alternatives. (Dept. of the Air Force, 1988) The Aircrew Training Research Division of the Armstrong Laboratory (AL/HRA) is actively engaged in research on the development of aircrew training simulators. Some simulators (and part-task trainers) have been placed with operational units for the purposes of aircrew research and development. A difficulty exists in that no widely accepted method of evaluating the benefit-cost impacts of these devices is in use. Since these simulators represent significant capital expenditures (Orlansky and Chatelier, 1983; Dept. of the Air Force, 1991; Dept. Of Defense, 1993), a method of evaluating their benefit-cost relationships would be helpful in evaluating their usefulness from both a management and a research perspective.

Since many training needs exist at the operational (squadron and wing) level, it is desired that simulators be evaluated for this purpose rather than strictly as research or developmental tools (Gray, Edwards and Andrews, 1993). With today's technology, it is possible to design a simulation system that can represent almost all tasks a pilot might be called on to perform. This includes some tasks that, due to legal, ethical, safety or security restrictions, cannot be easily practiced in the aircraft in peace time even though performance of the tasks would be expected during times of war (Dion and Bardeen, 1990; Prothero, 1991, p. 509). In addition, advances in communication and data base technology makes it possible to link such simulators in networks enabling many pilots to engage in the same simulated exercises (Rogers, Stephens and Oatman, 1991; Harvey and Schaffer, 1991; Gehl, Rogers, Miller and Rakolta, 1993).

The above factors led to the objective of developing a method of applying benefit-cost analysis to the acquisition of simulators which are designed for implementation at the operational (squadron or wing) level. These simulators would be appropriate for multiship activity and training (McDonald, et al, 1989; Harvey and Schaffer, 1991). The purpose of the research reported in this paper is to assist in the accomplishment of this objective.

BACKGROUND

In 1990 W. C. Moor developed a preliminary model for the benefit-cost evaluation of multiship simulator alternatives (Moor, 1991a; Moor 1991b; Moor and Andrews, 1992). The model demonstrated a complete method of benefit-cost analysis of multiship simulation alternatives and provided a means of computing the values for this analysis in a manner that is very straight forward (utilizing LOTUS 1-2-3™ spreadsheets). This model included the capacity to evaluate and compare multiple simulation environments as an explicit element. There were no differences in the computation method based on simulation environment.

The benefits portion of the overall model includes a number of terms which are unique to this project. For convenience of further exposition, Table 1 includes a definition of key terms. Figure 1 shows a flowchart of how the estimated benefits would be computed for a specific simulation environment or configuration. This benefits model has been implemented into a LOTUS 1-2-3™ spreadsheet to facilitate computations.

During the fall of 1992 and spring of 1993, the Multiship Research and Development (MultiRAD) program of research on the use of ground-based training being conducted at AL/HRA (Crane, 1993; Platt and Crane, 1993). The initial evaluation of the system was the Training Requirements Utility Evaluation (TRUE) (Berger and Crane, 1993). The TRUE project brought over 20 skilled, mission ready F-15 pilots to the AL/HRA facility at Williams AFB to evaluate the simulation systems being tested. Therefore, all elements required for a complete test of the benefits model were in one place over a period of 4 months (skilled pilots, experts in aircrew training systems (AL/HRA personnel), and experts in the design of aircraft simulation systems (AL/HRA personnel)). In addition, the developers of the simulation system provided an excellent source of cost information to exercise and refine the cost model.

The MultiRAD program included two F-15 cockpits, which were not identical, one each placed in the McDonnell-Douglas full field of view dome system (DOME) and the Armstrong Laboratory Display for Advanced Research and Training (DART) (Crane, 1993). These two approaches can easily be seen as two disparate simulation systems. This created the opportunity of evaluating the complete benefit-cost approach applied to a comparison of two "competing" simulation systems.

What is presented in the remainder of this report is a demonstration of the data collection necessary to fully implement the benefits component and the update and refinement of the cost component of the total benefits-cost model, thereby improving its capability for decision assistance. In addition, this total benefit-cost model is applied in a comparison of the DART-based MultiRAD simulation system to the DOME-based MultiRAD simulation system.

SYSTEM MODELING FOR BENEFIT-COST ANALYSIS

There is a general agreement (Maciariello, 1975; Pearce, 1983; Oxenfeldt, 1979) that a benefit-cost analysis includes:

1. A specification of the goal(s) or objective(s) which the program or system is intended to achieve.
2. An enumeration and definition of the alternatives which are proposed as mechanisms for reaching these goal(s).
3. A definition of the means of evaluating the benefits derivable from each alternative. This includes the definition of the means of converting benefits into quantitative (dollar measurable) terms.

Figure 1
Flowchart of Benefits Computation
Assumes a specific performance area and a specific simulation environment.

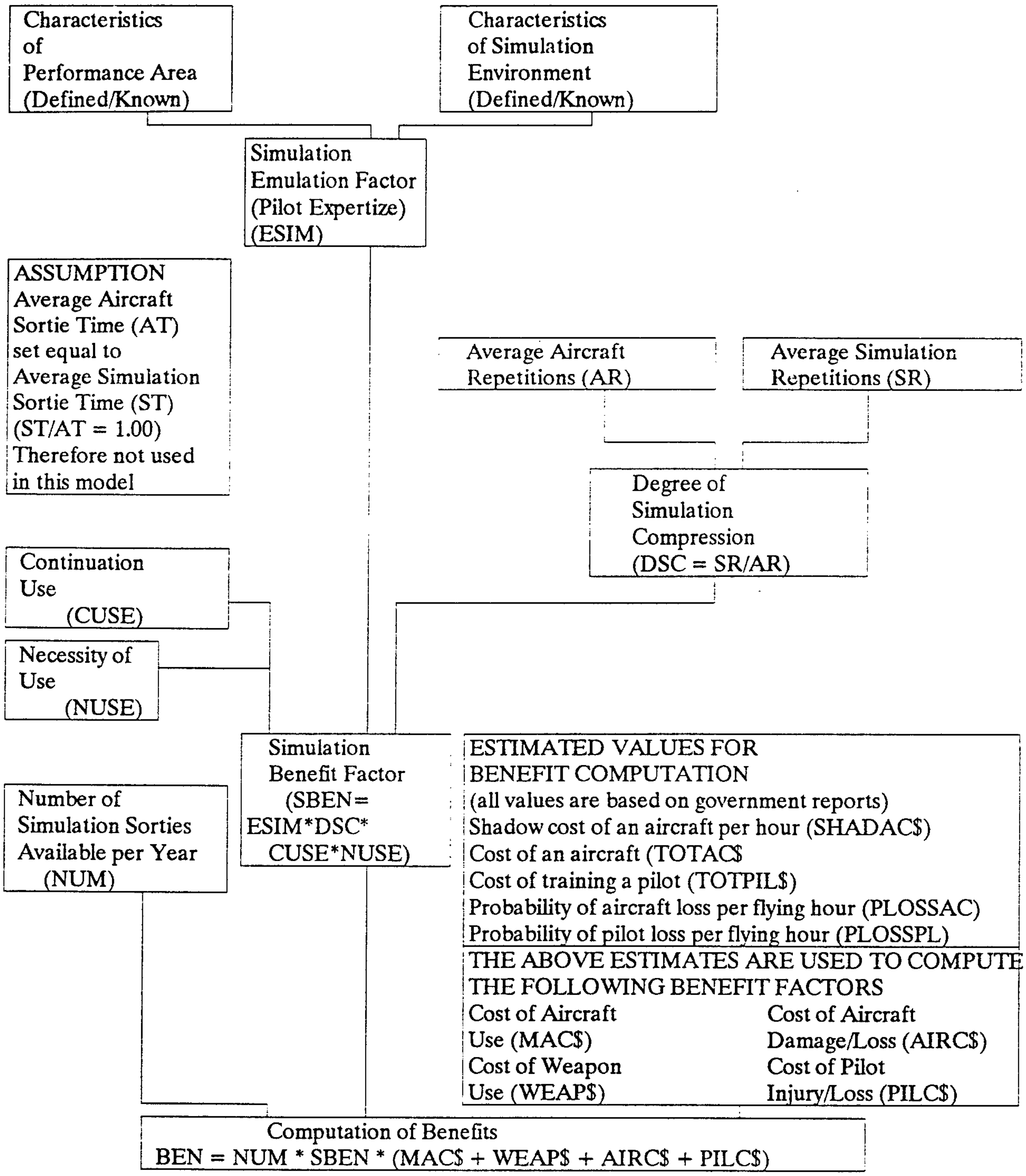


Table 1
Variable Identification and Definition
(Extracted from Moor, 1991a and Moor, 1991b)

Performance Area: An operational activity which would be required by a combat pilot and would be behaviorally complex enough that training emphasizing its acquisition and maintenance is appropriate. The Performance Area is identified as **PA(i)** where i refers to a specific performance area.

Continuation Use of the Simulator: The degree to which a simulator would be used to train in a performance area after initial skill training had been accomplished. The Continuation USE is identified as **CUSE(i)**.

Necessity of Use of the Simulator: The degree to which a simulator must be used to train in a performance area (usually because of extreme hazard/danger or legality of operation). The Necessity of USE is identified as **NUSE(i)**.

Emulation Capability of the Simulation Environment: The degree to which the simulation environment represents the actual environment experienced in the aircraft for the specific performance area. The Emulation capability of the SIMulation environment is identified as **ESIM(i)**.

Simulation Environment: The environment (inside the simulator) as experienced by the pilot. The SIMulation environment is identified as **SIM(j)**; where j refers to the specific simulation environment (different simulator).

Aircraft Training/Practice Sortie: A sortie where one, or more, of the performance areas would be practiced.

1. **Aircraft Sortie Duration** - the average time for such a sortie. The Aircraft sortie Time is identified as **AT(i)**

2. **Performance Area Iterations** - the number of times the specific performance area could be practiced per sortie. The Aircraft Repetitions are identified as **AR(i).**

Simulation Training/Practice Sortie: A simulation sortie devoted to the practice of one, or more, specific performance areas.

1. **Simulation Sortie Duration** - the average time for such a sortie. This time period is intended to be held equal to the corresponding aircraft sortie duration to facilitate later computations. The Simulation sortie Times are identified as **ST(i)**.

2. **Simulation Performance Area Iterations** - the number of times a specific performance area could be practiced per simulation sortie. The Simulation Repetitions are identified as **SR(i).**

Degree of Simulation Compression: Ratio of the number of times a given Performance Area can be practiced in a simulator versus an aircraft. The Degree of Simulation Compression is identified as **DSC(i)** and is computed by SR(i)/AR(i)

Simulation Benefit Factor: This factor is used directly in computing the overall benefits imputed to each organizational alternative. The Simulation BENefit factor is identified as **SBEN(i)** and is computed by ESIM(i)*CUSE(i)*NUSE(i)*DSC(i).

Table 1 (Concluded)
Variable Identification and Definition

Directly Measured Benefit Elements: These factors are based on the shadow costs for the use of aircraft and weaponry approximated by the marginal costs of this equipment.

1. **Marginal (incremental) Aircraft Cost** - Cost of flying the aircraft on a per sortie basis (or per hour, SHADAC$(i)), corrected for Performance Area if appropriate. The Marginal Aircraft Cost is identified as **MACS(i)**.

2. **Weaponry Cost** - Cost of using ammunition, weaponry or other consumables expended per aircraft sortie for each Performance Area. This cost would include a factor for all damage (peace time) due to the use of the weaponry. The WEAPonry cost is identified as **WEAPS(i).**

Indirectly Measured Benefit Elements: These factors are based on potential losses of pilots and aircraft used in flying sorties. They are a measure of risk rather than training.

1. **Aircraft Loss Cost** - Cost of loss of the aircraft as a function of its use in flying sorties of the specific Performance Area. This is a probability based measure computed by (Cost of an aircraft, TOTAC$)*(Probability of loss per sortie, PLOSSAC). The AIRcraft loss Cost is identified as **AIRCS(i).**

2. **Pilot Death Cost** - Cost of losing a pilot due to training accident as a function of his exposure to risk in specific Performance Areas. This is a probability based measure computed by (cost of the pilot, TOTPIL$)*(Probability of loss per sortie, PLOSSPL). The PILot death Cost is identified as **PILCS(i).**

Number of Simulation Sorties: The total number of simulation sorties that can be performed in a specified simulation environment for each Performance Area for each organizational alternative in a year (or other suitable time period). The NUMber of sorties is identified as **NUM(i).**

4. A definition of the means of evaluating the costs required to implement each alternative.
5. A completed analysis showing the computed incremental benefit/cost (B/C) ratios for all alternatives being evaluated. (Alternatively net benefits minus cost may be used as a basis for evaluating alternatives.)

For this study, all these conditions were met allowing the evaluation proposed by Moor and Andrews (1993) to be fully and completely exercised using the data collection procedures developed. The goal to be met was to maximize the simulation training available to the squadron mission-ready F-15 pilot. As noted previously, the MultiRAD simulation system developed at AL/HRA could be used to investigate the benefit-cost analysis method for the comparison of simulation alternatives.

In modeling and evaluating the simulation systems and organizational alternatives the author drew upon the experience and expertise of 5 AL/HRA personnel (two of whom were engineers who had developed the MultiRAD approach, two of whom were active USAF pilots who were developing the training mechanisms by which the MultiRAD could be used and one was a research psychologist who was directing the Operation TRUE activities). These experts helped in specifying the actual physical design of a MultiRAD simulator and in

constructing the organizational alternatives utilizing the MultiRAD which would be subjected to the benefit-cost evaluation.

The purpose of this evaluation was to determine an alternative which would be most beneficial in delivering simulation training capability to pilots at the squadron level. Alternatives were created to meet this goal which could be seen as satisfying the criteria shown in Table 2 (Moor and Andrews, 1992, p. 3).

Table 2

Criteria for Organizational Alternatives

1. Each alternative must be constructed in such a manner that it is mutually exclusive which respect to each other alternative. [Pearce, 1983]
2. Each alternative must be capable of providing multiship training/practice/maintenance of skills to all pilots within a definable segment of the Air Force.
3. Each alternative may include one, or more, simulation environments which may not be exclusive between alternatives.
4. The alternatives will be established with respect to a specific aircraft type and configuration.
5. The alternatives are intended to serve operational units (Wings or Squadrons) not units devoted primarily to training new or cross training pilots.

Four organizational alternatives were created. These alternatives and attributes in common among them are shown in Table 3.

The parameters of these organizational alternatives were combined with the criteria and assumptions that the average sortie duration would be 1.5 hours and the utilization rate per simulator would be 95% for squadron simulators and 85% for regional simulators (supported by the opinions of the experts being consulted) to determine the total number of sorties that could be "flown". The computation of benefits for a particular simulation system is directly dependent on the total number of simulation sorties possible. Obviously, this depends on the number of simulators expected to be in use and the operating schedule for that use. It is proposed that, when simulators are to be compared, operating conditions as nearly equal as possible be used (hours of operation, number of simulation cockpits, etc.). The only differences allowed would those technologically intrinsic to the simulator (required maintenance downtime, reliability, etc.). The values total number of sorties available for organizational alternatives (TOTNUMSQ for squadrons and TOTNUMWG for regional centers) are shown in Table 4 which shows the computation spreadsheet (NUMCALC.WK1) prepared for this purpose (Moor and Andrews, 1993).

Block diagrams were developed for all organizational alternatives and show the commercially available components of each simulator system. A representative block diagram is shown in Figure 2. The cost model, presented in a later section of this report, will refer back to these elements as well as the organizational designs to establish the total cost of the various alternatives.

Table 3

Organizational Alternative and Their Attributes

ORGANIZATIONAL ALTERNATIVES

1. Each F-15 squadron would be equipped with a pair of DART simulators. The simulators would be capable of intersquadron interactive linking (in pairs) for up to 6 v 6 combat exercises.
2. Each F-15 squadron would be equipped with a pair of DART simulators. There would be four regional centers for special simulation exercises and mission rehearsal. Each regional center would be equipped with four DART simulators. Each regional center would operate during the normal week between the hours of 0830 and 1430. The simulators would be capable of intersquadron (plus one region) interactive linking (in pairs) for up to 8 v 8 combat exercises.
3. Each F-15 squadron would be equipped with a pair of DOME simulators. The simulators would be capable of intersquadron interactive linking (in pairs) for up to 6 v 6 combat exercises.
4. Each F-15 squadron would be equipped with a pair of DOME simulators. There would be four regional centers for special simulation exercises and mission rehearsal. Each regional center would be equipped with four DOME simulators. Each regional center would operate during the normal week between the hours of 0830 and 1430. The simulators would be capable of intersquadron (plus one region) interactive linking (in pairs) for up to 8 v 8 combat exercises.

ATTRIBUTES IN COMMON

1. Each alternative is served by a Regional Data Base Development Center. This was viewed as necessary in order to maintain currency in the data bases in use and to allow for the development of specialized data bases for mission rehearsal purposes.
2. There would be two simulation systems available to each squadron currently equipped with the F-15.
3. There are approximately 15 squadrons (5 wings) of F-15's to be served. Assuming there are approximately 450 F-15's in active operational service and that the pilot manning ratio is 1.25 per aircraft and that there are approximately 24 to 28 aircraft per squadron, there would be approximately 35 pilots per squadron (plus flying rated officers not counted in the manning ratio). This yields an estimate of approximately 500 to 550 pilots to be served by the simulation alternative. (Department of the Air Force, 1982; International Institute for Strategic Studies, 1989; AIR FORCE Magazine, 1993)
4. There are approximately 50 working/flying hours in the current work week for pilots. Of these, no more than 5 to 6 hours would be available for additional simulation training (counting briefing, simulation runs, and debriefing).
5. All simulation training/practice, in the squadron, would be performed between 0700 and 1900 during the normal work week. Allowing for a 1 hour briefing before the simulation run and a 1.5 hour debriefing the simulator could be run between 0800 and 1730.
6. All sorties and simulation runs are performed by, at least, 2 plane (pilot) elements.
7. Each organizational alternative should provide for the use of ground control and two (or more) opponent aircraft (human or computer control).
8. All components used in the alternatives must be currently commercially available or be developed to the extent that commercial specifications can be stated.

BENEFITS ESTIMATION

The data collection questionnaires which were developed to assist in the benefits estimation are extensively discussed in Moor and Andrews (1993). These questionnaires were used, and evaluated and improved, during the course of this project.

A principal philosophy underlying the benefits estimation model is that each area of expertise associated with the design and use of a simulation system should be provided maximum input regarding that area of expertise but should not be allow to impact areas of benefit evaluation which do not fall into their area. That is, experts in the design and construction of simulation systems (engineers, computer scientists, etc. in the employ of the simulation builder) should be given maximum input in specifying what it is their simulation system can accomplish, experts in the use of simulation systems for training (educational psychologists, trainers, etc. not in the employ of the simulation builder) should be given maximum input in specifying how the simulation system should be used, and, experts in the area being trained (USAF pilots, etc.) should be given maximum input in specifying how well the simulation system accomplishes its purpose.

PERFORMANCE AREAS

The purpose of this research emphasizes the operational use of simulators, therefore a comparison that is not meaningful to pilots is not useful. Extensive research conducted using the F-15 simulators at McAir (Houck and Thomas, 1989; Houck, Thomas and Bell, 1991), has yielded an empirically derived set of "tasks" based on interviews with pilots that form the current basis for Performance Areas. These performance areas have the advantage of being meaningful to pilots who can compare the simulated environment to the environment they experience in the aircraft. In addition, these areas include some that are rarely encountered and not part of any training manual.

The set of performance areas is probably too large (27 areas) to grasp for the purposes of making benefit comparisons. The procedure followed is that, when a simulator is being evaluated, the developers of the simulator select those areas which are best presented by their system. The number created would probably be considerably smaller and would be most advantageous to that particular simulator.

This procedure was implemented by administering a questionnaire designed for this purpose (Moor and Andrews, 1993, p. 13) to a set of people most closely associated with the design of the MultiRAD system. The sample of experts included 4 engineers (3 of them USAF pilots) and two training development system AL/HRA personnel. These individuals did not distinguish the simulators based on visual (DART vs DOME) capability but used data base, control and operational characteristics which were the same for both versions.

The results of this questionnaire were analyzed using the decision making software CRITERIUM™ (Criterium Reference Guide, 1989). This required a translation of the questionnaire results from a 5-point scale to a 9-point scale (1 to 1 translation) but allowed pooling of the experts opinion not based on a simple arithmetic average of ordinal values. That is, the error of averaging ordinal values was removed from the

Table 4

Total Number of Simulation Sorties Available for the MULTIRAD Benefit – Cost Analysis

Assuming 15 squadrons and 4 wing/regional centers available for training.
TOTNUM is transferred to MULTBEN.WK1 for computation of benefits.

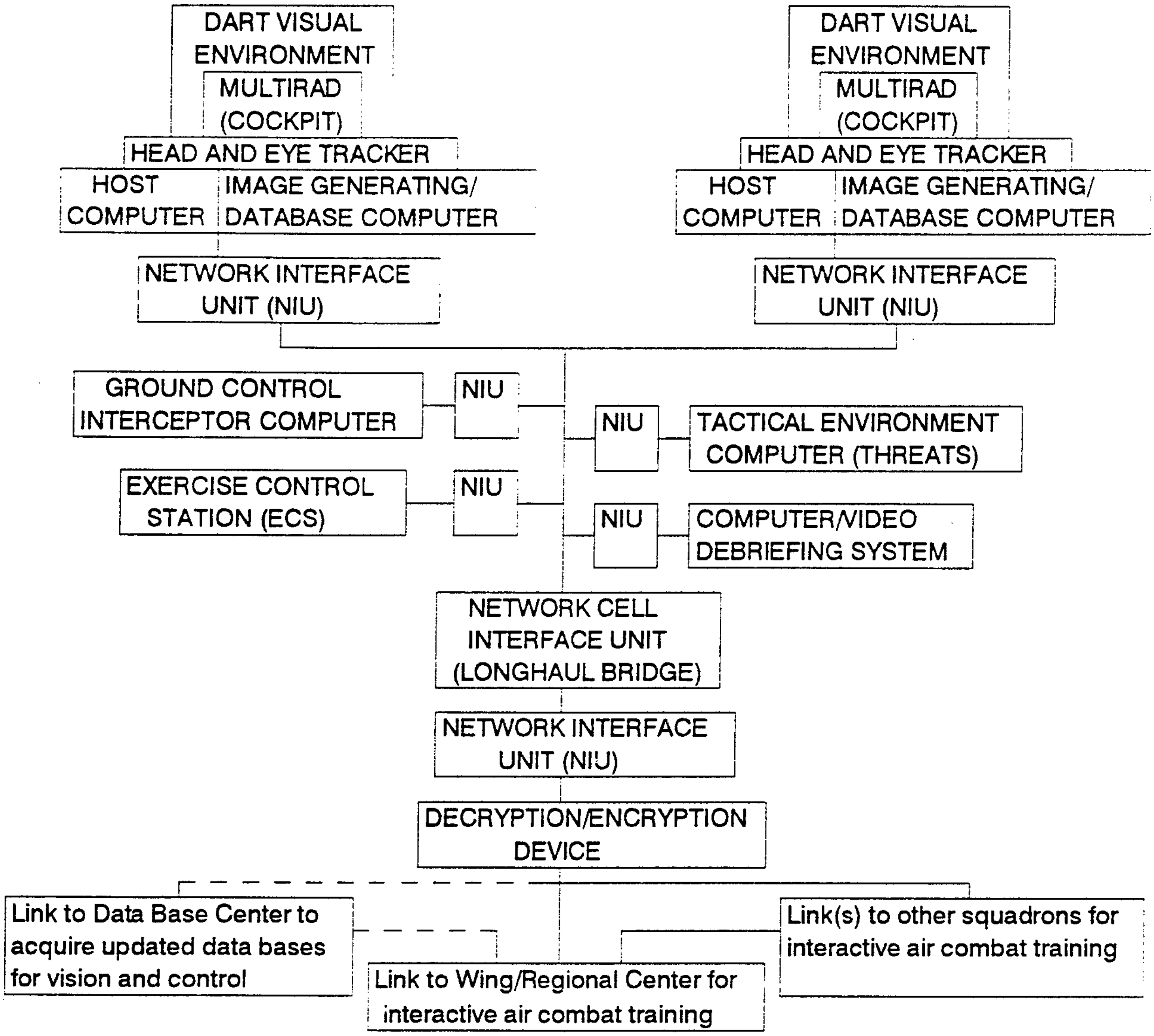
	UNIT LEVEL FOR COMPUTATIONS			
	SQUADRON		WING/REGIONAL	
	VARIABLE VALUE	RANGE NAME	VARIABLE VALUE	RANGE NAME
ORGANIZATIONAL CHARACTERISTICS:				
NUMBER OF SIMULATORS PER UNIT	2	NSIMSQ	4	NSIMWG
NUMBER OF UNITS	15	NUMSQ	4	NUMWG
OPERATING CHARACTERISTICS PER UNIT:				
NUMBER OF HOURS OPERATED PER DAY	12	NHRDYSQ	8	NHRDYWG
NUMBER OF DAYS OPERATED PER WEEK	5	NDYWKSQ	5	NDYWKWG
NUMBER OF WEEKS OPERATED PER YEAR	52	NWKYRSQ	52	NWKYRWG
SORTIE DURATION	1.5	SRTMSQ	1.5	SRTMWG
AVERAGE BRIEFING TIME PER SORTIE (HOURS	1	BRFTMSQ	1	BRFTMWG
AVERAGE DEBRIEFING TIME PER SORTIE (HOU	1.5	DBRFTMSQ	1.5	DBRFTMWG
UTILIZATION RATE (AVAILABILITY PER DAY) (stated as a decimal between 0.00 and 1.00)	95.00%	UTILSQ	85.00%	UTILWG
NUMBER OF SORTIES PER DAY PER SIMULATOR	6.01666666	NSORTSQ	3.11666666	NSORTWG
INTEGER NUMBER OF SORTIES PER DAY PER SIMULATOR	6	NNSORTSQ	3	NNSORTWG
TOTAL NUMBER OF SORTIES PER YEAR FOR THIS UNIT LEVI (this is used as TOTNUM(j) in the benefits computation)	46800	TOTNUMSQ	12480	TOTNUMWG

Figure 2

Graphical Model of Possible Organizational Alternative Component
Based on using the MULTIRAD simulation environment at the operational level

One pair of MULTIRAD simulators placed in each squadron.
Interactive Simulation Communications available with up to 3 other squadrons.
Links to Wing/Regional Center.
DART Basis for visual simulation.
Head and Eye Tracker available for each simulator.

This alternative would permit up to 12 human pilots and 4 computer generated aircraft at one time. Therefore a maximum of 16 aircraft could be configured for practice/training air combat sorties.



ranking of the performance areas. The pooled values for perceived relative capability of simulating performance areas are showing in Table 5 for the 12 most highly rated areas.

As may be observed from Table 5, there is a "natural" break separating the first 8 performance areas from the remainder. This was used to select the initial subset of performance areas to input to the remainder of the benefit estimation. Definitions of all performance areas are presented in Moor and Andrews (1993).

Table 5

Ranking of Performance Areas by Relative Acceptability

Rank	Relative Importance	Name of Performance Area
1	4.61%	Radar Employment/Sorting
2	4.40%	Multibogey, 4 or More
3	4.38%	Tactical Intercept
4	4.35%	Electronic ID
5	4.24%	TEWS Assessment
6	4.18%	Mission Debriefing
7	4.09%	Radar Lookout
8	4.07%	BVR Employment
9	3.92%	Chaff/Flare Employment
10	3.90%	Intraflight Comm.
11	3.88%	Tactics/Mission Plan & Brief
12	3.81%	Reaction to SAMs
12	3.81%	Reaction to AIs

Debriefing as a performance area poses some conceptual difficulties in the model for benefits estimation. The assumption underlying the conversion to dollar terms in this model is that the benefits accrue due to "flying" in the simulator. Since debriefing offers no possibility of such a conversion, it was removed as a performance area.

The activity of debriefing, however, was kept as an element for the overall benefit estimation of the MultiRAD system. The reason for this is that the system used for debriefing incorporated video tape recordings of the pilots actions in the simulator including a "God's Eye" (overhead, two dimension pattern) of the path of the aircraft being simulated. Clearly such a record for review and training is not available when an aircraft is actually being flown and offers a distinct benefit. The method of evaluating this benefit will be explained in a later section of this report.

DETERMINATION OF NUSE AND CUSE VALUES

Once the performance areas were selected for each simulator to be evaluated, experts in the training needs for the USAF were asked to provide an evaluation of the character of this training for mission ready pilots. Currently there are 4 categories used to evaluate each performance area (Moor and Andrews, 1993, Pp. 10-13). This evaluation would be used to provide the basis for numeric estimates for CUse and NUse and also

a basis for the number of times a particular performance area could be repeated in a simulation sortie versus an aircraft sortie.

The questionnaire to determine the character of the 7 performance areas (Moor and Andrews, 1993, p. 14) was administered to 3 mission ready, squadron pilot and 2 AL/HRA personnel where were retired USAF pilots. The results are shown in Table 9. Since these results offered no clear cut determination of the nature of several of the performance areas, a group interview was held with all 5 to reach a consensus determination. The results of this meeting are shown in the last column of Table 6.

Table 6

Evaluation of the Discrete versus Continuous (CUse/NUse)
Nature of the Performance Areas

PERFORMANCE AREAS EVALUATED	EXPERT EVALUATION A	B	C	D	E	DETERMINATION OF COMPOSITE VALUE
Beyond-Visual-Range Employment	C	C	C	D-II	D-II	C
Radar Employment/ Sorting	C	C	C	D-II	C/D-II	C
Electronic Identification (EID)	D-III	C	C	D-II	C	C
Radar Lookout	C	C	C	C	D-II/C	C
TEWS Assessment	C	C	C	D-II	D-III/C	C
Tactical Intercept	D-I	D-II	C	D-II	D-II	D-II
Multibogey, Four or More	D-III	D-II	C	D-II	D-III	D-III

The group interview also yielded necessary information concerning the average duration of a training sortie during which these performance areas would be practiced and, where applicable, multiple practices of the same area (AREP) could occur. Those performance areas designated as Continuous would not lend themselves to any increased exposure in a simulator and therefore were assigned a AREP value of 1.0 and a simulation repetition factor (SREP) value of 1.0. No training compression would occur when training in these areas in a simulator. The two performance areas, Tactical Intercept and Multibogey, which were identified as Discrete in nature, could be repeated more frequently in a simulator than is possible in an aircraft sortie. The consensus view of AREP and SREP for these two areas is shown in Table 7.

DETERMINATION OF ESIM VALUES

The values developed for the Emulation capability of the Simulator (ESIM) are the means by which expert pilot evaluations enter into the benefits estimation. The questionnaire by which the values are elicited is discussed in Moor and Andrews (1993, p. 18).

The MultiRAD environment was being extensively tested by Air Force pilots and ground controllers during Operation TRUE (Platt and Crane, 1993) under the guidance of AL/HRA. The directors of this project

included the questionnaires for pilots in the "debriefing" packets for these "subjects". This created a sample of 23 mission ready, squadron pilots who visited AL/HRA during the fall of 1992 and the spring of 1993. These experts formed a data base of people experienced in both the MultiRAD environment and the actual aircraft environment that could not otherwise be acquired.

Table 7

Repetitions of Performance Areas
Aircraft versus Simulation Sorties

NAME OF PERFORMANCE AREA	NUMBER OF REPETITIONS POSSIBLE AIRCRAFT SORTIE (AREP)	SIMULATION SORTIE (SREP)
Tactical Intercept	4	8
Multibogey, Four or More	3	6

These pilots felt that the simulation environment had a different capability depending on whether the simulator was being used for the acquisition of a skill or the maintenance of a skill, therefore the questionnaire asked for their evaluations concerning both. For purposes of this study, the weighted average of their evaluations was used. The distinction between acquisition and maintenance had not been foreseen when previous data was collected and therefore could not be maintained. The ESIM values acquired in this manner are shown on Table 8.

Table 8
Determination of MultiRAD ESIM Values By Mission Ready Pilots

TASKS EVALUATED	ESIM VALUES FOR THE VISUAL ENVIRONMENT DOME	DART
Beyond-Visual-Range Employment	0.6409	0.5593
Radar Employment/Sorting	0.6625	0.6098
Electronic Identification (EID)	0.6591	0.6376
Radar Lookout	0.6045	0.5674
TEWS Assessment	0.6000	0.6197
Tactical Intercept	0.5636	0.4770
Multibogey, Four or More	0.6000	0.5098
NUMBER OF PILOTS	11	12

DETERMINATION OF NUMBER OF SORTIES BY PERFORMANCE AREA

The method for determining the "average" number of simulation sorties devoted to each performance area recognizes that no training sortie can ever be devoted to exactly one performance area. The assumption is made, however, that in the long run (one year) the average proportion of time spent on a given performance area can be counted by a sortie (or time) based measure. Therefore the number of sorties is estimated per

performance area by taking the proportion of time that expert opinion indicates should be devoted to that area relative to all other performance areas and multiplying it by the total number of sorties (TOTNUM) possible for that simulator.

This procedure was implemented by administering a questionnaire designed for this purpose to a set of people most closely associated with the design of the MultiRAD system. The sample of experts included 4 engineers (3 of them USAF pilots) and two training development system AL/HRA personnel. These experts made an abbreviated paired comparison of the 7 performance areas against the criterion of importance of training at the squadron level using the questionnaire developed in Moor and Andrews (1993, p. 19).

The results of this questionnaire were analyzed using the decision making software CRITERIUM™ (Criterium Reference Guide, 1989). The output of this analysis is a proportion of relative importance for each performance area. These proportions are shown in Table 9 and are used as the multipliers for TOTNUM to determine the relative number of sorties (NUM) for each performance area (decimal fractions are maintained in this case). The total sorties per performance area for each organizational alternative are shown in the complete benefits estimation matrix in the Appendix.

Table 9
Proportions of Time for Performance Areas

PERFORMANCE AREAS EVALUATED	DART TIME PROPORTIONS FOR EACH PERFORMANCE AREA	DOME TIME PROPORTIONS FOR EACH PERFORMANCE AREA
Beyond-Visual-Range Employment	17.63%	17.72%
Radar Employment/Sorting	13.05%	14.38%
Electronic Identification (EID)	6.36%	7.27%
Radar Lookout	9.21%	10.78%
TEWS Assessment	5.56%	8.19%
Tactical Intercept	18.15%	29.06%
Multibogey, Four or More	30.03%	12.60%
TOTAL	99.99%	100.00%

BENEFIT CONVERSION FACTORS

The creation of the benefits estimation for each organizational alternative depends on the shadow price of flying the F-15 aircraft (estimated by the marginal cost of operating existing aircraft) as well as the "savings" accruing due to not losing aircraft or pilots in flying mishaps. The values used for these estimates are shown in Table 10. All of these values have been converted to their 1993 estimates by using the CPI figures presented by Air Force Magazine (1993, p. 37) and the Directorate of Engineering and Services (1988, p. 6)

Table 10

Benefit Conversion Values

Shadow cost of an aircraft per hour (SHADAC$) Estimated based on maintenance costs and AVPOL costs contained in the USAF budget. (Department of the Air Force, 1991; 1992; Institute for Simulation & Training, 1990)	$2,400
Cost of an aircraft (TOTAC$): Estimated based on USAF budget figures for the last year in which F-15 aircraft (C/D models were being acquired. (Department of the Air Force, 1988: 1989)	$45,900,000
Cost of the pilot (TOTPIL$): Estimated by the U. S. General Accounting Office (1987)	$9.605.000
Probability of aircraft loss per flying hour (PLOSSAC) Estimated based on accident rates compiled by the USAF Safety Center (Dept. of the Air Force, 1992)	0.0000308
Probability of pilot loss per flying hour (PLOSSPL) Estimated based on accident rates compiled by the USAF Safety Center (Dept. of the Air Force. 1992) supplemented by the assumption that loss of life would occur in one third of the incidents that resulted in aircraft destruction.	0.00001

ESTIMATION OF THE BENEFITS ACCRUING DUE TO DEBRIEFING

The performance area of debriefing does not lend itself to a benefits estimation which is based on the shadow cost of flying an aircraft. Therefore. while the debriefing system available with the MultiRAD was maintained as a source of benefit, a separate estimation of benefit was made. Intensive interviewing with 3 pilots at AL/HRL led to the conclusion that the "value" of debriefing was a multiplier of the hours spent learning as a result of debriefing. It was felt that this multiplier was best estimated as 3. That is, an hour of debriefing in the system was worth three hours of debriefing under normal flying conditions.

Therefore, the method of computing the benefit of debriefing may be shown by the following equation: (3-1)X(Average hourly wage of pilots)X(Hours spent debriefing).

Assumptions made in order to apply this equation are:

1. The average rank of pilot was Captain. with 12 years in service.
2. The average pilot was married, drawing full benefits and allowances.
3. The hours of normal work per year are 2080.
4. The average annual compensation of this pilot is:

($3273 + $175 + $650 + $557) = $55,860

The hourly rate is $55860/208 = $26.86

The total number of sorties flown (as computed by the spreadsheet NUMCALC.WK1) were used to compute the total benefits.

A. Squadron systems only:

(46800 sorties)X(1.5 debriefing hours per sortie)X(hourly rate)

Debriefing Benefits = $1,885,275 per year

B. Systems including Wing/Regional Centers

(59280 sorties)X(1.5 debriefing hours per sortie)X(hourly rate)

Debriefing Benefits = $2,388,015 per year

These values are added to the total benefits estimates for all other performance areas to determine the final total benefits estimates.

TOTAL BENEFITS ESTIMATES

Table 11 shows the benefits estimated for the four organizational alternatives considered by this study. The benefits matrix (in LOTUS 1-2-3™ format) is available to the interested reader (NEWBEN.WK1) and is shown in the Appendix in its entirety.

Table 11

Benefits Estimation for the MultiRAD Simulation System
(Debriefing shown as separate element)

DOME No Wing/Region Center 1	DOME including Wing/Region Centers 2	DART No Wing/Region Center 3	DART including Wing/Region Centers 4
$17,885,594	$22,655,086	$14,342,910	$18,167,686
$31,170,395	$39,482,500	$27,063,593	$34,280,551
$13,487,252	$17,083,852	$9,473,817	$12,000,168
$26,147,675	$33,120,389	$21,841,690	$27,666,141
$13,151,462	$16,658,518	$11,129,963	$14,097,953
$89,905,220	$113,879,946	$47,524,037	$60,197,113
$41,499,237	$52,565,700	$84,037,569	$106,447,587
$233,246,838	$295,445,995	$215,413,581	$272.857,203
$1,885,275	$2,388,015	$1,885,275	$2,388,015
$235,132,113	$297,834,010	$217,298,856	$275,245,218

COST ESTIMATION

The cost model developed for this method of benefit-cost evaluation has been reviewed by AL/HRA personnel and applied in the analysis of an existing simulator (Moor and Andrews, 1993). There is no indication that this model has any inherent fault. This cost model was drawn directly from Air Force procedures (Dept. of the Air Force, AFM Reg 173-15, 1988) and a costing approach developed in reference to an earlier version of these procedures (Knapp and Orlansky, 1983).

The costs to be estimated are a combination of the purchase prices to be paid for the simulators and their component parts, specialized buildings for the simulators, communications, networking and computer controls for interaction and the wages and salaries of the personnel required to operate the simulator systems. In actual application some of these costs would be a matter of contract specification, others would be determined by existing wage rates and overhead structures and still others would be construction or reallocation of physical asset costs. The procedure followed for this study was to estimate all costs at market value as of 1993 for "new" or newly acquired assets (including manpower).

The data for the cost model came from interviews with four AL/HRL personnel (all four were professional engineers, two were also USAF pilots) who were very familiar with the commercial simulation device market; Air Force cost estimating manuals (Directorate of Engineering and Services, 1988; Grant and Thornley, 1987; Waier, 1991); Civil Service and military pay rates [AIR FORCE Magazine, 1993]; and the operating configurations discussed with Figure 2. A number of assumptions were necessary in order that the cost data acquired could be cast into the model in use. The assumptions are shown in Table 12.

Table 12 also shows the numerical values estimated for all component parts of the four organizational alternatives as well as specific assumptions made concerning individual components. These cost values were placed in the master cost estimation matrix (COLLECT$.WK1) (Moor and Andrews, 1993), which is shown in the Appendix. The total cost values from this spreadsheet are carried forward into the benefit-cost analysis.

BENEFIT-COST COMPARISONS

The results of this benefit-cost analysis applied to four organizational alternatives based on the MultiRAD simulation system are shown in Table 14. This table is derived from the individual values estimated by the benefits and cost matrices and shows specific monetary factors necessary to complete the analysis. This table is drawn from a LOTUS 1-2-3™ spreadsheet (SUMCOST.WK1) developed for this purpose. This spreadsheet is "linked" to both the benefits and the cost spreadsheet so that as these are completed the benefits-cost analysis is completed.

CONCLUSIONS

This project applied, in complete detail, a method for the benefit-cost analysis to the acquisition of simulators which are designed for implementation at the operational (squadron or wing) level. Table 14 demonstrates the clarity with which the results of this can be presented to a decision maker choosing between or among competing simulators. It should be repeated that, while the numeric figures presented for the benefits of each alternative are regarded as valid for purposes of comparison, they should not be interpreted as indicating the absolute value of a given simulation system.

This analysis show that a MultiRAD DART-based simulation system with a pair of simulators in each squadron and four regional/wing centers with four simulators at each center would be preferred by a considerable margin over its nearest MultiRAD alternative. It does not necessarily show that the MultiRAD is to be preferred over other, as yet, unanalyzed simulation systems.

Table 13

Space and Cost Estimates for Simulation Centers

Operating Characteristics and Configurations

1. Physical Facilities and Staffing

(Staffing keyed to estimated civil service grade levels, step 4 within level, 28% fringe benefits)
Staffing assumes that squadron simulation centers would run on a 16 hour/day, 5 day/week basis.
The first 2 hours and the last 2 hours would be for maintenance, calibration, warm-up, etc.
Regional centers would operate on a 12 hour/day, 5 day/week basis.
Data Base Development Center would run on an 8 hour/day, 5 day/week basis.
Data Base Center would also provide expertise to maintain concurrency and updates for equipment.

	Cost Estimate	Notes and Comments (SQ. FT.)
A. Squadron Training Centers		
a) Physical Facilities		
Simulation Room – 2 DARTs (20'x44'x20')		880
plus space for ECS, etc. (10'x20'x20')	$388,958	200
Simulation Room – 2 Domes (26'x50'x 30')		1300
plus space for ECS, etc. (10'x20'x30')	$534,871	200
Briefing Room (12'x10')	$36,347	120
Debriefing Room (12'x10')	$36,347	120
Office/Archive/Review Room (10'x12')	$36,347	120
Equipment/Storage/Support Room (8'x10')	$24,231	80
b) Staffing		
Manager/Simulation Trainer (1, GS 9)	$39,126	
Technician/Operator (2, GS 5)	$53,207	
Technician/Trouble Shooter (1, GS 7)	$31,985	
TOTALS – per squadron simulation facility		
9 year capital items – DART simulation facilities	$522,230	
9 year capital items – Dome simulation facilities	$668,143	
Annual personnel costs, either facility	$124,317	
B. Wing Training Centers		
a) Physical Facilities		
Simulation Room – 4 DARTS (45'x45'x20')		2025
(includes ECS space, etc.)	$717,263	
Simulation Room – 4 Domes (50'x50'x30')		2500
(includes ECS space, etc.)	$882,284	
Briefing Room (12'x10')	$36,347	120
Debriefing Room (12'x10')	$36,347	120
Office/Archive/Review Room (16'x20')	$96,925	320
Equipment/Storage/Support Room (8'x10')	$24,231	80
b) Staffing		
Manager/Simulation Trainer (1, GS 9)	$39,126	
Technician/Operator (3, GS 5)	$79,811	
Technician/Trouble Shooter (1, GS 7)	$31,985	
TOTALS – per wing/regional simulation facility		
9 year capital items – DART simulation facilities	$911,113	
9 year capital items – Dome simulation facilities	$1,076,133	
Annual personnel costs, either facility	$150,921	
C. Data Base Development/Concurrency Maintenance Center		
a) Physical Facilities		
Data Base Work Stations (6, 5'x6')	$71,731	180
(includes computer work stations)		
Offices (6, 8'x10')	$162,598	480

Table 13

Space and Cost Estimates for Simulation Centers

Data Base Work Station Computers (13, "Sun-like")	$390,000	
Meeting Room/Archive (15'x30')	$136,301	450
Master Computer Room (20'x30')	$217,898	600
Data Base Development Main-Frame Computer	$2,000,000	
Display/Study Simulator (includes one complete DART (or Dome) simulator for testing/validation of data bases)		
DART (25'x25'x20')	$226,583	625
Dome (30'x30'x30')	$322,121	900
b) Staffing		
Manager/Technical Director (1, GS 13)	$67,470	
Engineer/Developer/Analyst/Concurrency Specialist		
(1, GS 12)	$56,739	
(1, GS 11)	$47,342	
(1, GS 9)	$39,126	
(2, GS 7)	$53,207	
Technician/Programmer/Concurrency Specialist		
(1, GS 9)	$39,126	
(2, GS 7)	$53,207	
(2, GS 5)	$63,969	
Clerical (2, GS 3)	$41,124	
TOTALS – for the data base development/concurrency maintenance facility		
9 year capital items – DART simulation facilities	$1,205,110	
9 year capital items – Dome simulation facilities	$1,300,649	
3 year capital items	$2,000,000	
Annual personnel costs, either facility	$461,309	

ADDITIONAL ASSUMPTIONS ABOUT BUILDING COST ESTIMATES.

1. All building estimates are based on the Air Force Construction Guide (Ref. 53, 1988).
   a. Corrections for inflation are made by using the CPI table I developed. The correction factors presented in Ref. 53 are clearly wrong in the light of historical evidence. This correction factor for the time period from 10/1/90 to 10/1/93 is 1.1323
   b. Building size corrections for cost estimates per square foot are made using the method presented in the Ref. XX.
   c. Specific comparison buildings and corrections are shown in the notes column above.
2. Estimates for Squadron DART/Dome Simulation Rooms
   Most similar to High Bay Hangers with the additions of:
   a. Dual Wide-Band cabling and communication system prewiring. — $3.40 per sq. ft.
   b. Two sets of systems furniture. — $3,800.00 per set.
   c. Extra air conditioning – 2 tons — $2,273.00 per ton
   d. Correction factor for size (based on original size of hangers)

Hanger size	35000 sq. ft.	
DART room size (880+200)		1080 sq. ft.
1080/35000 =	0.03085714	Correction factor = 1.3
Dome room size (1300+200)		1500 sq.ft.
1500/35000=	0.04285714	Correction factor = 1.3

   e. Correction factor for inflation — 1.1323
   f. Basic cost of basis facility — $126.00 per sq. ft.
   g. Estimate for loose furnishings and contingencies — 10.00% of basic est.
3. Estimates for Wing/Regional DART/Dome Simulation Rooms
   Most similar to High Bay Hangers with the additions of:
   a. Dual Wide-Band cabling and communication system prewiring. — $3.40 per sq. ft.
   b. Four sets of systems furniture. — $3,800.00 per set.

Table 13

Space and Cost Estimates for Simulation Centers

c. Extra air conditioning – 4 tons			$2,273.00 per ton
d. Correction factor for size (based on original size of hangers)			
Hanger size	35000 sq. ft.		
DART room size		2025 sq. ft.	
2025/35000 =	0.05785714	Correction factor = 1.3	
Dome room size		2500 sq.ft.	
2500/35000=	0.07142857	Correction factor = 1.3	
e. Correction factor for inflation			1.1323
f. Basic cost of basis facility			$126.00 per sq. ft.
g. Estimate for loose furnishings and contingencies			10.00% of basic est.
4. Estimates for Data Base Center DART/Dome Simulation Rooms			
Most similar to High Bay Hangers with the additions of:			
a. Dual Wide–Band cabling and communication system prewiring.			$3.40 per sq. ft.
b. One set of systems furniture.			$3,800.00 per set.
c. Extra air conditioning – 2 tons			$2,273.00 per ton
d. Correction factor for size (based on original size of hangers)			
Hanger size	35000 sq. ft.		
DART room size	625 sq. ft.		
625/35000 =	0.01785714	Correction factor = 1.3	
Dome room size	900 sq.ft.		
900/35000=	0.02571428	Correction factor = 1.3	
e. Correction factor for inflation			1.1323
f. Basic cost of basis facility			$126.00 per sq. ft.
g. Estimate for loose furnishings and contingencies			10.00% of basic est.
5. Estimates for all other office/laboratory space for squadron, wing/regional and data base centers.			
Most similar to Data Processing Administrative facilities			
a. Correction factor for size (based on original size of facility)			
Original facility size	21000 sq. ft.		
In all cases the correction factor will be 1.3			
b. Correction factor for inflation			1.1323
c. Basic cost of basis facility			$107.00 per sq. ft.
d. Estimate for loose furnishings and contingencies			20.00% of basic est.
e. Special estimate for data base center mainframe computer room includes 2 tons of extra airconditioning			
f. Special estimate for data base center systems furniture			
8 Sets at	$3,800.00 per set		

(Note: An estimate for fringe benefits for civil service is 28% and military is 22%
(Note: An estimate for the reliability of the computers is .98
These estimates are a composite of information provided byAL/HRA personnel
In all cases the "high" end of the range of values which were received.

Table 14

Overall Benefit–Cost Summary Results

ASSUMPTIONS AND COMPUTATIONAL FACTORS

1.	Number of squadrons to be equipped:	15
2.	Number of wing/regional centers to be equipped:	4
3.	All alternatives will include the data base/concurrency center.	
4.	Interest rate:	5.00%
5.	Economic life of buildings (years):	9
6.	Residual value for buildings:	50.00%
7.	Economic life for non–buildings (years):	3
8.	Residual value for non–buildings:	10.00%
9.	Capital recovery factor – 9 year items:	0.14069008
10.	Capital recovery factor – 3 year items:	0.3672085646
11.	Net present worth factor for 9 years:	7.1078216756

BASIC COST ELEMENTS

	DART Equipped Squadron	Dome Equipped Squadron	DART Equipped Wing
Annual Cost	$1,674,417	$3,389,417	$3,001,021
9 Year Cost Items	$2,722,230	$12,268,143	$5,311,113
9X Year Cost Items	$22,763	$22,763	$28,109
3 Year Cost Items	$5,591,000	$6,091,000	$9,601,000

	Dome Equipped Wing	DART Equipped Data Base Center	Dome Equipped Data Base Center
Annual Cost	$5,915,021	$1,465,409	$2,522,909
9 Year Cost Items	$22,676,133	$2,305,110	$7,100,649
9X Year Cost Items	$28,109	$71,785	$71,785
3 Year Cost Items	$10,601,000	$5,661,000	$5,911,000

TOTAL SYSTEM COST ESTIMATES

(All configurations include the cost of the data base center)

	15 DART SQUADRONS NO WINGS	15 DART SQUADRONS WITH 4 WINGS	15 DOME SQUADRONS NO WINGS	15 DOME SQUADRONS WITH 4 WINGS
Annual Cost	$26,581,664	$38,585,748	$53,364,164	$77,024,248
9 Year Cost Items	$43,138,560	$64,383,012	$191,122,794	$281,827,326
9X Year Cost Items	$413,230	$525,666	$413,230	$525,666
3 Year Cost Items	$89,526,000	$127,930,000	$97,276,000	$139,680,000

Table 14

Overall Benefit–Cost Summary Results

ESTIMATED COST EQUIVALENCIES FOR THE CONFIGURED SYSTEMS

	15 DART SQUADRONS NO WINGS	15 DART SQUADRONS WITH 4 WINGS	15 DOME SQUADRONS NO WINGS	15 DOME SQUADRONS WITH 4 WINGS
Estimated Total Annual Equivalent Cost	$63,627,563	$87,717,247	$104,279,814	$150,829,965
Estimated Total Present Equivalent Cost	$452,253,372	$623,478,552	$741,202,323	$1,072,072,493

ESTIMATED BENEFIT EQUIVALENCIES FOR THE CONFIGURED SYSTEMS

	15 DART SQUADRONS NO WINGS	15 DART SQUADRONS WITH 4 WINGS	15 DOME SQUADRONS NO WINGS	15 DOME SQUADRONS WITH 4 WINGS
Estimated Total Annual Equivalent Benefit (including debriefing)	$217,298,856	$275,245,218	$235,132,113	$297,834,010
Estimated Total Present Equivalent Benefit (including debriefing)	$1,544,521,519	$1,956,393,927	$1,671,277,129	$2,116,951,032

ESTIMATED BENEFIT–COST EQUIVALENCIES FOR THE CONFIGURED SYSTEMS

	15 DART SQUADRONS NO WINGS	15 DART SQUADRONS WITH 4 WINGS	15 DOME SQUADRONS NO WINGS	15 DOME SQUADRONS WITH 4 WINGS
BENEFIT/COST RATIO				
Annual Equivalencies	3.415	3.138	2.255	1.975
Present Equivalencies	3.415	3.138	2.255	1.975
NET BENEFIT – COST				
Annual Equivalencies	$153,671,293	$187,527,971	$130,852,299	$147,004,045
Present Equivalencies	$1,092,268,147	$1,332,915,375	$930,074,806	$1,044,878,539

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APPENDIX

Benefits Estimation Matrix

Cost Estimation Matrix

APPENDIX TABLE A

BENEFITS ESTIMATION MATRIX – PART ONE

Benefits computation matrix showing the names of the Performance Areas (PA), Continuation Use (CUSE) values values and Necessity of Use (NUSE) values for the MultiRAD simulator system comparison study. RANGE NAMES for spreadsheet identification are as shown.

INPUT (Continuous (C) Versus Discrete (DX) as shown) NAMES OF PERFORMANCE AREAS	Performance Areas (i)	INPUT Continuation Use CUSE(i)	RANGE NAME	INPUT Necessity of Use NUSE(i)	RANGE NAME
RADAR LOOKOUT – C	1	1.00	CUSE1	1.00	NUSE1
BEYOND–VISUAL–RANGE (BVR) EMPLOYMENT – C	2	1.00	CUSE2	1.00	NUSE2
TACTICAL ELECTRONIC WARFARE SYSTEM (TEWS) ASSESS. – C	3	1.00	CUSE3	1.00	NUSE3
RADAR EMPLOYMENT/SORTING – C	4	1.00	CUSE4	1.00	NUSE4
ELECTRONIC IDENTIFICATION (EID) – C	5	1.00	CUSE5	1.00	NUSE5
TACTICAL INTERCEPT – D2	6	1.00	CUSE6	1.00	NUSE6
MULTIBOGEY, FOUR OR MORE – D3	7	1.00	CUSE7	1.00	NUSE7
Enter the names of the perforamnce areas (tasks) that are to serve as the basis for this evaluation.		Enter the value of 1.00 if the simulator can be used to maintain skills in this area for the mission ready pilot. Enter 0.50 if the simulator can only be used to train the initial acquisition of skills.		Enter the value of 2.00 if the simulator can be used to train a skill that cannot be trained in the aircraft. Enter 1.00 if simulator can used in parallel with the aircraft. Enter 0.0 if the simulator should not be used.	

NOTE: For this study, the debriefing system was regarded as a major element of benefit. A separate computation was performed for this element.

APPENDIX TABLE A

BENEFITS ESTIMATION MATRIX – PART TWO

Benefits computation matrix showing the values for the Simulation Emulation (ESIM) variables and the Aircraft Sortie Duration and Repetition of Performance Areas factors. RANGE NAMES for spreadsheet identification are as shown.

INPUT

Using the average values (acquisition and maintenance of skills).

Matrix of Values for Emulation Measures

ESIM(i,j)

Simulation Interfaces (j)

DOME No Wing/Region	RANGE 1 NAME	DOME including Wing/Region Centers	RANGE 2 NAME	DART No Wing/Region	RANGE 3 NAME	DART including Wing/Region Centers	RANGE 4 NAME
0.6045	ESIM11	0.6045	ESIM12	0.5674	ESIM13	0.5674	ESIM14
0.6409	ESIM21	0.6409	ESIM22	0.5593	ESIM23	0.5593	ESIM24
0.6000	ESIM31	0.6000	ESIM32	0.6197	ESIM33	0.6197	ESIM34
0.6625	ESIM41	0.6625	ESIM42	0.6098	ESIM43	0.6098	ESIM44
0.6591	ESIM51	0.6591	ESIM52	0.6376	ESIM53	0.6376	ESIM54
0.5636	ESIM61	0.5636	ESIM62	0.4770	ESIM63	0.4770	ESIM64
0.6000	ESIM71	0.6000	ESIM72	0.5098	ESIM73	0.5098	ESIM74

These values should come from interview or questionnaire evaluations performed by expert pilots. They should be scaled from 0.0000 to 1.0000

Aircraft Measures

INPUT Aircraft Sortie Time ATIME(i)	RANGE NAME	INPUT Aircraft Repetitions AREP(i)	RANGE NAME
1.50	ATIME1	1	AREP1
1.50	ATIME2	1	AREP2
1.50	ATIME3	1	AREP3
1.50	ATIME4	1	AREP4
1.50	ATIME5	1	AREP5
1.50	ATIME6	4	AREP6
1.50	ATIME7	3	AREP7

This should be the average length of the sortie during which this task would be trained in the aircraft.

This should be the number of the task could be fully repeated in an aircraft sortie.

APPENDIX TABLE A

BENEFITS ESTIMATION MATRIX – PART THREE

Benefits computation matrix showing the values for Simulation Sortie Duration and Repetition of Performance Areas factors. RANGE NAMES for spreadsheet identification are as shown.

INPUT Note: STIME(i) is held = ATIME(i) Simulation Sortie Time STIME(i)	RANGE NAME	INPUT: Simulation Repetitions SREP(i,J) — SIMULATION INTERFACE DOME No Wing/Region 1 RANGE NAME	DOME including Wing/Region Centers 2 RANGE NAME	DART No Wing/Region 3 RANGE NAME	DART including Wing/Region Centers 4 RANGE NAME
1.50	STIME1	1 SREP11	1 SREP12	1 SREP13	1 SREP14
1.50	STIME2	1 SREP21	1 SREP22	1 SREP23	1 SREP24
1.50	STIME3	1 SREP31	1 SREP32	1 SREP33	1 SREP34
1.50	STIME4	1 SREP41	1 SREP42	1 SREP43	1 SREP44
1.50	STIME5	1 SREP51	1 SREP52	1 SREP53	1 SREP54
1.50	STIME6	8 SREP61	8 SREP62	8 SREP63	8 SREP64
1.50	STIME7	6 SREP71	6 SREP72	6 SREP73	6 SREP74

This should be the average length of a simulator sortie designed to practice this task.

Each entry should be the average number of times this task may be fully repeated in the particular simulator interface being evaluated.

APPENDIX TABLE A

BENEFITS ESTIMATION MATRIX – PART FOUR

Benefits computation matrix showing intermediate benefit values computed as a check on results.
RANGE NAMES for spreadsheet identification are as shown.

OUTPUT

Simulation Benefit Factors (SBEN)

Computation Equation: SBEN(i,j) = ESIM(i,j)*(SREP(i,j)/AREP(i))*(STIME(i)/ATIME(i))*(CUSE(i)*NUSE(i))

SIMULATION INTERFACE

DOME No Wing/Region 1 RANGE NAMI	DOME including Wing/Region Centers 2 RANGE NAMI	DART No Wing/Region 3 RANGE NAMI	DART including Wing/Region Centers 4 RANGE NAME
0.60450 SBEN11	0.60450 SBEN12	0.56740 SBEN13	0.56740 SBEN14
0.64090 SBEN21	0.64090 SBEN22	0.55930 SBEN23	0.55930 SBEN24
0.60000 SBEN31	0.60000 SBEN32	0.61970 SBEN33	0.61970 SBEN34
0.66250 SBEN41	0.66250 SBEN42	0.60980 SBEN43	0.60980 SBEN44
0.65910 SBEN51	0.65910 SBEN52	0.63760 SBEN53	0.63760 SBEN54
1.12720 SBEN61	1.12720 SBEN62	0.95400 SBEN63	0.95400 SBEN64
1.20000 SBEN71	1.20000 SBEN72	1.01960 SBEN73	1.01960 SBEN74

This contains intermediate values
computed by the spreadsheet.
DO NOT make entries.

APPENDIX TABLE A

BENEFITS ESTIMATION MATRIX – PART FIVE

OUTPUT

RANGE NAMES for spreadsheet identification are as shown.

NUM(i,j) is a function of the total number of simulation sorties (TOTNUM) and the proportionate fractions (PROP(i,j) generated by expert opinion.

Note that NUM(i,j) is also a function of scheduling AND absolute throughputs achievable by the organizational alternative being evaluated.

Computation Equation: NUM(i,j) = TOTNUM(j)*PROP(i,j)

NUM(i,j) per year

SIMULATION INTERFACE

DOME No Wing/Region 1	RANGE NAME	DOME including Wing/Region Centers 2	RANGE NAME	DART No Wing/Region 3	RANGE NAME	DART including Wing/Region Centers 4	RANGE NAME
5045.04	NUM11	6390.384	NUM12	4310.28	NUM13	5459.688	NUM14
8292.96	NUM21	10504.416	NUM22	8250.84	NUM23	10451.064	NUM24
3832.92	NUM31	4855.032	NUM32	2606.76	NUM33	3301.896	NUM34
6729.84	NUM41	8524.464	NUM42	6107.4	NUM43	7736.04	NUM44
3402.36	NUM51	4309.656	NUM52	2976.48	NUM53	3770.208	NUM54
13600.08	NUM61	17226.768	NUM62	8494.2	NUM63	10759.32	NUM64
5896.8	NUM71	7469.28	NUM72	14054.04	NUM73	17801.784	NUM74
TOTNUM1		TOTNUM2		TOTNUM3		TOTNUM4	
46800		59280		46800		59280	

INPUT

Proportion of Sorties (PROP(i,j)

Proportion of the total sorties available in the organizational alternative which should be devoted to Performance Area I. Note: This may also refer to a proportion of one sortie or some combination of sorties. It is intended as an overall allocation of effort based on expert opinion.

SIMULATION INTERFACE

P.A.	DOME No Wing/Region 1	RANGE NAME	DOME including Wing/Region Centers 2	RANGE NAME	DART No Wing/Region 3	RANGE NAME	DART including Wing/Region Centers 4	RANGE NAME
1	0.1078	PROP11	0.1078	PROP12	0.0921	PROP13	0.0921	PROP14
2	0.1772	PROP21	0.1772	PROP22	0.1763	PROP23	0.1763	PROP24
3	0.0819	PROP31	0.0819	PROP32	0.0557	PROP33	0.0557	PROP34
4	0.1438	PROP41	0.1438	PROP42	0.1305	PROP43	0.1305	PROP44
5	0.0727	PROP51	0.0727	PROP52	0.0636	PROP53	0.0636	PROP54
6	0.2906	PROP61	0.2906	PROP62	0.1815	PROP63	0.1815	PROP64
7	0.1260	PROP71	0.1260	PROP72	0.3003	PROP73	0.3003	PROP74

APPENDIX TABLE A

BENEFITS ESTIMATION MATRIX – PART SIX

Key Data Elements for Benefits Estimation

RANGE NAMES for spreadsheet identification are as shown.

OUTPUT		INPUT		OUTPUT	
Aircraft Use Cost per sortie				Benefit Conversion Factors Weapons Use Determined by task description and analysis.	
Computation Equation MAC$(i) = SHADAC$(i)*ATIME(i)				No Computation Equation	
MAC$(i)	RANGE NAME	Shadow cost of an aircraft per hour (SHADAC$):	$2,400.00	WEAP$(i)	RANGE NAME
$3,600.00	MAC$1	Cost of an aircraft (TOTAC$):	$45,900,000.00	$0.00	WEAP$1
$3,600.00	MAC$2			$0.00	WEAP$2
$3,600.00	MAC$3	Cost of the pilot (TOTPIL$):	$9,605,000.00	$0.00	WEAP$3
$3,600.00	MAC$4			$0.00	WEAP$4
$3,600.00	MAC$5	Probability of aircraft loss per flying hour: (PLOSSAC)	0.0000308	$0.00	WEAP$5
$3,600.00	MAC$6			$0.00	WEAP$6
$3,600.00	MAC$7	Probability of pilot loss per flying hour: (PLOSSPL)	0.00001	$0.00	WEAP$7
				Cost of Weapons Use on a per task basis when trained in the aircraft. Determined by task description and analysis.	

APPENDIX TABLE A

BENEFITS ESTIMATION MATRIX – PART SEVEN

Key Data Elements for Benefits Estimation

RANGE NAMES for spreadsheet identification are as shown.

Loss of Aircraft Computation Equation	Loss of Pilot Computation Equation
AIRC$(i)=TOTAC$*PLOSSAC*ATIME(i)	PILC(i) = TOTPIL$*PLOSSPL*ATIME(i)

AIRC$(i)	RANGE NAME	PILC$(i)	RANGE NAME
$2,120.58	AIRC$1	$144.08	PILC$1
$2,120.58	AIRC$2	$144.08	PILC$2
$2,120.58	AIRC$3	$144.08	PILC$3
$2,120.58	AIRC$4	$144.08	PILC$4
$2,120.58	AIRC$5	$144.08	PILC$5
$2,120.58	AIRC$6	$144.08	PILC$6
$2,120.58	AIRC$7	$144.08	PILC$7

TOTAL ESTIMATED BENEFITS

Each benefit element = NUM(i,j)*SBEN(i,j)*{MAC$(i)+WEAP$(i)+AIRC$(i)+PILC$(i)}

This is the summation of all elements of the first alternative.

$233,246,838.28

Since these values represent the final output of the computation,
no range names are assigned to these locations

DOME No Wing/Region	DOME including Wing/Region Centers	DART No Wing/Region	DART including Wing/Region Centers
1	2	3	4
$17,885,594.82	$22,655,086.78	$14,342,910.34	$18,167,686.44
$31,170,395.38	$39,482,500.82	$27,063,593.00	$34,280,551.14
$13,487,252.07	$17,083,852.62	$9,473,817.48	$12,000,168.80
$26,147,675.75	$33,120,389.28	$21,841,690.75	$27,666,141.62
$13,151,462.31	$16,658,518.92	$11,129,963.65	$14,097,953.96
$89,905,220.83	$113,879,946.38	$47,524,037.09	$60,197,113.64
$41,499,237.12	$52,565,700.36	$84,037,569.04	$106,447,587.45
$233,246,838.28	$295,445,995.15	$215,413,581.35	$272,857,203.04

APPENDIX TABLE B

Summary of All Cost Components, Individually and Summed for Organizational Alternatives

COST CATEGORIES/ELEMENTS (Cost category structure is identical to that presented in Knapp and Orlansky (1983))	DESCRIPTIVE NOTES (See SPACE_EST.WK1)	Preliminary Cost Estimate (per unit cost)	Life
A. RESEARCH AND DEVELOPMENT	Assume all items would be	------	–
(See descriptive notes)	purchased based on designs	------	–
	currently on hand in AL	------	–
	or would be purchased from	------	–
	commercial firms. There	------	–
	should be minimal R & D costs	------	–
	except for :	------	–
5. Prototype Manufacturing	3 year life	$50,000	3
7. P/C/D Test and Evaluation	3 year life	$100,000	3
B. INITIAL INVESTMENT	See my description of	------	–
1. Production	component parts of the	------	–
a. Nonrecurring	simulation alternatives	------	–
(3) Industrial facilities	for descriptions. (SPAC_EST.WK1)	------	–
Buildings to house simulation devices	This includes a specification of	Shown by	9
(4) Other – Capital Equipment with a 3 year life	room and building sizes proposed.	Center	3
b. Recurring		------	–
Acquisition costs		------	–
MULTIRAD Cockpit	Assume 9 year life for basic configuation	$800,000	9
Annual Update for MULTIRAD Cockpit	Annual Consumption	$120,000	a
DART Visual Environment	Assume 9 year life for basic configuation	$300,000	9
Annual Update for DART	Annual Consumption	$50,000	a
Dome Visual Environment	Assume 9 year life for basic configuation	$5,000,000	9
Annual Update for Dome	Annual Consumption	$150,000	a
Head and Eye Tracker	Assume 3 year life	$50,000	3
Host Computer	Assume 3 year life	$100,000	3
Image Generating/Database Computer	Assume 3 year life	$1,750,000	3
DART – 6 Channels		------	–
Image Generating/Database Computer	Assume 3 year life	$2,000,000	3
Dome – 7 Channels		------	–
Network Interface Unit	Assume 3 year life	$30,000	3

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COST CATEGORIES/ELEMENTS (Cost category structure is identical to that presented in Knapp and Orlansky (1983))	DESCRIPTIVE NOTES (See SPACE_EST.WK1)	Preliminary Cost Estimate (per unit cost)	Life
Network Cell Interface Unit	Assume 3 year life	$40,000	3
Ground Control Interceptor Computer	Assume 3 year life	$20,000	3
Exercise Control Station (ECS)	Assume 3 year life	$1,000,000	3
Tactical Environment (Threats) Computer	Assume 3 year life	$150,000	3
Decryption/Encryption Device	Assume 3 year life	$4,000	3
Communication Lines	Assume 3 year life	$10,000	3
(minimum 1.544 Mb/Sec)		-----	–
Briefing/Debriefing Computer and Displays	Assume 3 year life	$180,000	3
includes Video and Playback Devices		-----	–
Data Base Development – Main Frame Computer	Assume 3 year life	$2,000,000	3
c. Initial Spares and Repair Parts	Stated as a percentage of the above.	5.00%	a
5. Data		-----	–
b. Technical	Assume 3 year life	$10,000	3
c. Instruction Materials	Assume 3 year life	$12,000	3
7. System/Project Management	Annual Consumption	$5,000	3
10. Initial Training		-----	–
a. Instructors (On site Operators)	Assume 9 year life for initial training	Combined, shown	9X
b. Maintenance Personnel	Assume 9 year life for initial training	by Center	9X
12. Other		N/A	–
C. OPERATING AND SUPPORT		-----	–
1. Direct Costs		-----	–
a. Instructional Costs		-----	–
(1) Pay and allowances		-----	–
(a) Instructors (Simulation Operators)	See WCM description of simulation	Combined,	a
(b) Supervisors, Admin, and Support Personnel	components for the wage grade	shown by	a
(c) Maintenance Personnel	structures for personnel involved.	Center	a
(2) Other Government Personnel Costs	Estimated as a percent of salary costs	28.00%	a
(3) Consumption		-----	–
(c) Utilities	Annual Consumption	$5,000	a
(d) Instructional Materials	Annual Consumption	$1,000	a

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(e) Other	Annual Consumption	-----	a
(4) Replenishments, Spares	Annual Consumption	5.00%	a
(5) Modification Material	Annual Consumption	5.00%	a
(7) Other Purchased Services	Annual Consumption	$10,000	a
(8) Other – Update Training	Annual Consumption	By Center	a
b. Training Activity Costs		-----	–
(1) Pay and Allowances		N/A	–
(2) Other Government Personnel Costs	Annual Consumption	22.00%	–
(3) Other		N/A	–
e. Other Direct Costs		N/A	–
2. Indirect Costs		-----	–
a. Base Operations		N/A	–
b. inventory and Supply Management		N/A	–
c. Military Family Housing Support		N/A	–
d. Command Support Costs		N/A	–
e. Other Indirect Costs		N/A	–

TOTAL ESTIMATED COSTS:

CAPITAL ITEMS – 9 YEAR LIFE
CAPITAL ITEMS – 3 YEAR LIFE
NON–CAPITAL ITEMS – 9 YEAR LIFE
ANNUAL CONSUMPTION

APPENDIX TABLE B

Summary of All Cost Components, Individually and Summed for Organizational Alternatives

CATEGORY I. D.	Cost Estimate per Squadron Center (DART)	Cost Estimate per Squadron Center (Dome)	Cost Estimate per Wing/ Regional Center (DART)	Cost Estimate per Wing/ Regional Center (Dome)	Cost Estimate for Data Base/ Concurrency Center (DART)	Cost Estimate for Data Base/ Concurrency Center (Dome)
A.	-----	-----	-----	-----	-----	-----
A.	-----	-----	-----	-----	-----	-----
A.	-----	-----	-----	-----	-----	-----
A.	-----	-----	-----	-----	-----	-----
A.	-----	-----	-----	-----	-----	-----
A.	-----	-----	-----	-----	-----	-----
A.	-----	-----	-----	-----	-----	-----
A.5.	$50,000	$50,000	$100,000	$100,000	$50,000	$50,000
A.7.	$100,000	$100,000	$200,000	$200,000	$100,000	$100,000
B.	-----	-----	-----	-----	-----	-----
B.1.	-----	-----	-----	-----	-----	-----
B.1.a.	-----	-----	-----	-----	-----	-----
B.1.a.(3).	-----	-----	-----	-----	-----	-----
B.1.a.(3).	$522,230	$668,143	$911,113	$1,076,133	$1,205,110	$1,300,649
B.1.a.(4).	-----	-----	-----	-----	-----	-----
B.1.b.	-----	-----	-----	-----	-----	-----
B.1.b.	-----	-----	-----	-----	-----	-----
B.1.b.	$1,600,000	$1,600,000	$3,200,000	$1,600,000	$800,000	$800,000
B.1.b.	$240,000	$240,000	$480,000	$240,000	$120,000	$120,000
B.1.b.	$600,000	-----	$1,200,000	-----	$300,000	-----
B.1.b.	$100,000	-----	$200,000	-----	$50,000	-----
B.1.b.	-----	$10,000,000	-----	$20,000,000	-----	$5,000,000
B.1.b.	-----	$300,000	-----	$600,000	-----	$150,000
B.1.b.	$100,000	$100,000	$200,000	$200,000	$50,000	$50,000
B.1.b.	$200,000	$200,000	$400,000	$400,000	$100,000	$100,000
B.1.b.	$3,500,000	-----	$7,000,000	-----	$1,750,000	-----
B.1.b.	-----	-----	-----	-----	-----	-----
B.1.b.	-----	$4,000,000	-----	$8,000,000	-----	$2,000,000
B.1.b.	-----	-----	-----	-----	-----	-----
B.1.b.	$210,000	$210,000	$270,000	$270,000	$180,000	$180,000

APPENDIX TABLE B

Summary of All Cost Components, Individually and Summed for Organizational Alternatives

CATEGORY I. D.	Cost Estimate per Squadron Center (DART)	Cost Estimate per Squadron Center (Dome)	Cost Estimate per Wing/ Regional Center (DART)	Cost Estimate per Wing/ Regional Center (Dome)	Cost Estimate for Data Base/ Concurrency Center (DART)	Cost Estimate for Data Base/ Concurrency Center (Dome)
B.1.b.	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
B.1.b.	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000
B.1.b.	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000
B.1.b.	$150,000	$150,000	$150,000	$150,000	$150,000	$150,000
B.1.b.	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000
B.1.b.	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
B.1.b.	-----	-----	-----	-----	-----	-----
B.1.b.	$180,000	$180,000	$180,000	$180,000	$180,000	$180,000
B.1.b.	-----	-----	-----	-----	-----	-----
B.1.b.					$2,000,000	$2,000,000
B.1.c.	$397,700	$902,700	$717,700	$1,635,700	$337,700	$590,200
B.5.	-----	-----	-----	-----	-----	-----
B.5.b.	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
B.5.c.	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000
B.7.	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
B.10.	-----	-----	-----	-----	-----	-----
B.10.a.	$22,763	$22,763	$28,109	$28,109	$71,785	$71,785
B.10.b.	-----	-----	-----	-----	-----	-----
B.12.	N/A	N/A	N/A	N/A	N/A	N/A
C.	-----	-----	-----	-----	-----	-----
C.1.	-----	-----	-----	-----	-----	-----
C.1.a.	-----	-----	-----	-----	-----	-----
C.1.a.(1).	-----	-----	-----	-----	-----	-----
C.1.a.(1).(a).	$124,317	$124,317	$150,921	$150,921	$461,309	$461,309
C.1.a.(1).(b).	-----	-----	-----	-----	-----	-----
C.1.a.(1).(c).	-----	-----	-----	-----	-----	-----
C.1.a.(2).	28.00%	28.00%	28.00%	28.00%	28.00%	28.00%
C.1.a.(3).	-----	-----	-----	-----	-----	-----
C.1.a.(3).(c).	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
C.1.a.(3).(d).	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000

APPENDIX TABLE B

Summary of All Cost Components, Individually and Summed for Organizational Alternatives

CATEGORY I. D.	Cost Estimate per Squadron Center (DART)	Cost Estimate per Squadron Center (Dome)	Cost Estimate per Wing/ Regional Center (DART)	Cost Estimate per Wing/ Regional Center (Dome)	Cost Estimate for Data Base/ Concurrency Center (DART)	Cost Estimate for Data Base/ Concurrency Center (Dome)
C.1.a.(3).(e).	-----	-----	-----	-----	-----	-----
C.1.a.(4).	$397,700	$902,700	$717,700	$1,635,700	$237,700	$590,200
C.1.a.(5).	$397,700	$902,700	$717,700	$1,635,700	$237,700	$590,200
C.1.a.(7).	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
C.1.a.(8).	$1,000	$1,000	$1,000	$1,000	$5,000	$5,000
C.1.b.	-----	-----	-----	-----	-----	-----
C.1.b.(1).	N/A	N/A	N/A	N/A	N/A	N/A
C.1.b.(2).	22.00%	22.00%	22.00%	22.00%	22.00%	22.00%
C.1.b.(3).	N/A	N/A	N/A	N/A	N/A	N/A
C.1.e.	N/A	N/A	N/A	N/A	N/A	N/A
C.2.	-----	-----	-----	-----	-----	-----
C.2.a.	N/A	N/A	N/A	N/A	N/A	N/A
C.2.b.	N/A	N/A	N/A	N/A	N/A	N/A
C.2.c.	N/A	N/A	N/A	N/A	N/A	N/A
C.2.d.	N/A	N/A	N/A	N/A	N/A	N/A
C.2.e.	N/A	N/A	N/A	N/A	N/A	N/A
TOTAL COSTS						
9 YR CAPITAL	$2,722,230	$12,268,143	$5,311,113	$22,676,133	$2,305,110	$7,100,649
3 YR CAPITAL	$5,591,000	$6,091,000	$9,601,000	$10,601,000	$5,661,000	$5,911,000
9 YR SPECIAL	$22,763	$22,763	$28,109	$28,109	$71,785	$71,785
ANNUAL	$1,674,417	$3,389,417	$3,001,021	$5,915,021	$1,465,409	$2,522,909

Comparisons of Vocal Patterns of M. mullata in Different Housing Conditions

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Final Report

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Comparisons of Vocal Patterns of M. mullata in Different Housing Conditions

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Abstract

Patterns of vocalizations of an important research primate, the rhesus monkey *Macaca mulatta*, were compared across six captive living conditions in order to determine whether characteristics of this primate's housing are manifest in its vocalizations. This study was a continuation of previous research in which it was established that free-ranging groups of *M. mulatta* communicate vocally under natural conditions by means of at least nine acoustically distinguishable calls (excluding infant calls).
Call types and their functional significance vary with behavioral contexts. The information transmitted in rhesus calls appears to include spatial location and identity, predator alarm, degrees of agressive threat, degrees of defensive distress, solicitation of aid, and appeasement/gratification. Vocal records may thus reflect the influence of both transient and long-term conditions affecting captive rhesus. The results of this study indicate that differences in housing conditions are manifest in amount and kind of vocalization, and in the temporal relations among kinds of vocalization.

Comparisons of Vocal Patterns of M. mullata in Different Housing Conditions

B. E. Mulligan

INTRODUCTION

Vocal communication among animals has been for many years a subject of considerable scientific interest, especially vocal behavior of non-human primates (e.g., Cheney and Seyfarth, 1992; Snowdon, Brown, and Petersen, 1982). The goals our research with the rhesus monkey, *Macaca mulatta*, have been both basic and pragmatic, *viz.*, to establish the vocal repertoire of *M. mulatta*, as it occurs under natural conditions, to serve as a foundation for the evaluation of their vocal behavior under captive, laboratory conditions. Realization of this goal provides an objective and non-invasive approach to the assessment of both transient and long-term influences on the psychological health of rhesus macaques employed as laboratory research subjects. The present study was the first application of this approach. It sought to determine whether differences in commonly used types of captive primate housing are manifest in the vocal behavior of this important research animal.

The first acoustical studies of rhesus vocalizations were conducted by Rowell (1962) and Rowell and Hinde (1962) on a captive colony of 22 animals. They distinguished between two general vocal classes , agonistic "noises" and mostly non-agonistic "clear calls". Thirteen years later, Erwin (1975) cited this work as "...the best description available..." of a highly variable vocal system that is extremely difficult to classify on either acoustical or functional grounds. In fact, Rowell and Hinde (1962) took the position that

their acoustical analyses did not separate rhesus vocalizations into exclusive call categories and they presented some evidence of sounds they said to be "transitional" between call categories. Erwin (1975) likewise noted that vocalizations of rhesus may contain mixtures of tonal clear calls with atonal noises. Indeed, he suggested that rhesus vocalizations function primarily to signal the caller's emotive condition.

Rhesus agonistic "screams" were extensively studied by Gouzoules, Gouzoules, and Marler (1984) in a large, free-ranging colony on Cayo Santiago. Contrary to previous findings, Gouzoules *et al.* found that sounds emitted during agonistic encounters were acoustically divisible into five discrete call categories each of which functions as a representational signal. Calls were found to be associated with status of the opponent (dominance rank or matrilineal relatedness) and level of aggression. Because they did not observe that either scream type or probability of subsequent behavior of the receiver varies with the caller's level of arousal level, they concluded that arousal information is not a primary informational component of rhesus screams.

Most recently, Hauser (1992) reported a study on the rhesus "coo" vocalization, a tonal, or clear call that is said to function as a "social contact" signal that contributes to group cohesiveness. Recordings were made from the colony on Cayo Santiago. The call acoustic structure of the call was reported to consist of closely spaced (about 400 Hz) harmonically related narrow bands below about 10 kHz. Call duration was found to vary between 100 and 650 msec. Remarkably, the members of one matriline were found to produce coos that were consistently more "nasal" than coos emitted by other animals. Nasality was defined acoustically as the level of noise between bands in the call. While it is interesting that nasality appeared to be limited to a single

matrilineal line, it was not determined whether monkeys respond differentially to this condition.

It is implicit in the above discussion that the vocal repertoire of *M.mulatta* was not established in 1991 when our investigations began. Preliminary observations in 1991 of vocalizations of laboratory-housed rhesus suggested the existence of some differences between their calls and those reported in the literature. However, it was not possible for us to determine whether these differences were an effect of laboratory housing, or perhaps a result of the improved analytical capabilities of the instrumentation that we were using, or due to some other factors. It was clear that the natural vocal repertoire of the rhesus macaque would require extensive study before meaningful conclusions could be reached concerning vocal behavior in laboratory-housed animals. At present, our classification of the vocal repertoire of *M. mulatta,* though not complete, has distinguished the properties of its major catagories (refer to Appendix I) which constitute the basis for the present study.

METHODOLOGY

Rhesus vocal behavior reflects both transient and long-term influences. Animals respond vocally to events taking place within their environments including interactions among themselves and humans (e.g., feeding, removal of an animal, etc.). It was the intent of the present study to minimize transient human-introduced influences so that vocal records would more clearly reflect differential effects of housing conditions. We believe this to be the first study in which continuous vocal records of captive primates were used to examine such effects.

Recordings of captive *M. mulatta* vocalizations were made in four housing sites at the Armstrong Laboratory (Brooks AFB) and in two housing sites at a primate research facility operated by LABS, Inc., Yemassee, SC. Vocal data obtained in these six sites were analyzed and compared on the basis of acoustical and behavioral classifications previously established on free-ranging groups of *M. mulatta* on Morgan Island (operated by LABS, Inc.) off the coast of South Carolina. This 500 acre, densely vegetated island provides an open environment for more than 4000 rhesus macaques forming about 32 social groups. Acoustical and video recordings of animals on Morgan Island were made over a two year period. Analyses of these recordings provided a "natural", or normative basis for the present study.

Recording Sites:

Four of the sites used in this study contained caged animals. Three of these (sites B, C, and D) were in-door rooms and one (site A) was an out-door

facility. Two sites (E and F) contained unconstrained groups of animals within circular, out-door corrals (diameter about 40 ft) equipted with structures for climbing, shelter, etc. Recordings in each site began between 10 and 11 a.m, 2 to 3 hours after completion of feeding and cleaning in cage areas.

Site A: an out-door facility with roof covering two long rows of adjacent, chain-link cages divided by a central walkway. Floor and walkway were concrete. Outside wall coverings could be partially raised or lowered depending on wheather conditions. Floor area in each cage was about 16 ft^2, height extending about 6 ft from floor to ceiling. This arrangement enabled visual contact on all sides and provided space for unimpeded movement of several individuals within an enclosure. The microphone was positioned on a tripod about 3 ft above the floor at a point along the walkway approximately in the middle of the enclosures. Record level was set such that moderate level sounds generated at the farthest enclosure in either direction would be detectable.

Adult animals were caged singly or in pairs. This group contained 49 adults (8 males; 49 females) and 9 juveniles. Animals had been moved to this facility about 5 weeks prior to recording. Previously, they had resided for six years in open housing, grouped in harems and serving as breeding stock.

Sites B, C, D: closed rooms containing two-levels of stacked cages placed side-by-side around walls with a cluster of stacked cages in the center of each room. This arrangement provided a rectangular free space, or walkway, between outer and central cages, and enabled visual contact between animals located on opposite sides of the walkway. Floor areas of the three in-door rooms were approximately 500 ft^2 (site B), 960 ft^2 (site C), and 336 ft^2 (site

D). Surfaces of floors (concrete or tile), walls (tile or sheet rock), and ceilings (sheet rock) were sealed with expoxy or polyurithane paint. The microphone was supported by a tripod about 3 ft. above the floor and located at a point on the walkway that optimized reception within each room.

All animals in each room were individually housed in stainless steal cages that comply with US DHHR guidelines: "Guide for the Care and Use of Laboratory Animals" , Public Health Service NIH Pub.No. 86-23 (1985). Cages of several sizes were used. In site B, cage dimensions were 53"L x 32"W x 81.5"H and 76"L x 38"W x 64"H. In site C, cage dimensions were 24"L x 36"W x 28"H and 30"L x 32"W x 32"H. In site D, cage dimensions were 30"L x 32"W x 32"H. All cages provided floor areas of 6 ft^2 or greater. Light-dark cycles in each room was 12/12 and ambient temperatures were approximately constant at about 36^{0}C.

Site B contained 21 animals (19 males; 2 females) ranging in age between 3 to 16 years (mean age about 7 yrs). Before being moved to this site, animals were used in laser surgery eye research. Animals had resided in site B for about 10 months prior to the present study and all were said to have normal vision and to be in good health.

Site C contained 100 animals (65 males; 35 females) ranging in age between 3 and 19 years (mean age about 8 yrs). This group consisted of animals returned from various research laboratories. All were said to be in good health. They had been housed in this room for about 2 years prior to the present study.

Site D contained 27 males ranging in age between 3 and 7 years (mean age about 5 yrs). At the time of the present study, these animals had resided in this room for about 1.5 years and were serving as subjects in non-invasive behavioral research. They were said to be in good health. Four animals were

removed from their home cages to another room for testing on the same day that recording for this study was done. The animal removed last was returned to its home cage in site D about 30 minutes before recording began.

Sites E and F: out-door, elliptical-shaped corrals (approximate area 2,000 ft^2) surrounded by metal walls about 20 ft high with floors of grass and areas of exposed sandy soil. Each corral contained apparatus for climbing, shelter, etc. A covered observation poarch was attached near the wall top of each corral. Pairs of corrals were adjoined by a connecting enclosure designed to facilitate caretaker entrance, non-injurious animal capture, etc.
Each of sites thus consisted of two connected corrals. Recording time was divided approximately evenly between corrals in each site. The microphone was located on the observation poarches.

Each corral contained one social group consisting of 20 to 30 individuals. Each group contained 1 alpha male, 1 alpha female, 2-3 sub-adult males, 8-20 adult females, plus juveniles. Animals within corrals had been together as stable social groups (no additions to groups other than births) for about 10 years prior to the present study.

Acoustical Recording and Analysis System:

Vocalizations and noise originating within sites were recorded using a Sennheiser MKH 416 P48 supercardioid/lobe condenser microphone (frequency response 40-20000 Hz) feeding a Sony TCD-D10 Pro II digital audio recorder sampling at 48 kHz. The microphone was held in a shock mount and, for out-door recordings, it was enclosed in a Sennheiser MZW 60 blimp windscreen.
Acoustical analyses were performed using a Sony PCM-2700 recorder to read the prerecorded digital tapes into a Kay CSL model 4300 spectrographic computer

board operating at a rate of 51,200 samples per second within a 80486 machine with SVGA display. Additional structural analyses were performed by means of Engineering Design's "Signal" and "RTS" programs using a Global LABS I/O board sampling at a rate of 48K per second in conjunction with a DSP accelerator board for real-time displays. These systems permitted temporal, spectral, and three dimensional graphic and numeric analyses of vocal acoustical structures.

Conversion of sound recordings into temporal sequences of categorical events (i.e., moment-by-moment occurrences of each type of sound) was accomplished by real-time auditory and visual monitoring of signals while inputing keyboard responses to a computer program written specifically to record relevant categorical and temporal information coded for specific keys. Machine upper limit for recording events was a rate of about 18 per second, in excess of actual event rates. The event-recording program also enabled precise syncronization with acoustical tape recordings. Real-time auditory monitoring of acoustical recordings was done by either headphone or speaker outputs from the Sony PCM 2700 recorder. Real-time visual monitoring of acoustical spectrograms on a high resolution computer screen was accomplished by means of the Engineering Design RTS system cited above.

Procedure:

The initial problem of establishing a basis for distinguishing among rhesus macaque vocalizations involved (a) recording vocalizations from normal, free-ranging social groups of animals over a sufficiently long period of time (about 2 years) to obtain a representative sample, (b) analyses of acoustical structures (e.g., changes in spectral distribution of energy over time, call durations, rise-decay times, etc.) of these vocalizations in order to identify reliable patterns, (c) establishing similarity of acoustic patterns as an

objective means to separate vocalizations into distinctive call categories, and (d) determining the natural behavioral context and function of each category of call from field observations made both at the time of recording and later after acoustical segmentation of vocalizations into call categories. A preliminary description of the major catagories of rhesus vocalizations has been reported (Mulligan, 1963) and is attached as appendix I to this report.

Acoustical recordings made for the purpose of comparing vocal patterns across housing conditions were made within each of the sites described above. Data were extracted from tape recordings in seven categories of acoustical events, *viz.*, Coo, Echoic Bark, Low Bark, Gruff Bark, Shrill Cry, Scream, and Noise. The non-vocal category "Noise" is sound generated by intense actions of animals *vis-a-vis* some object in their environment (e.g., cage). The category "Scream" includes without distinction all instances of several several categories of defensive calls ("Clicks", "Shrill Screams", "Screams", and "Blasts"). The category "Coo" includes both appeasement and gratification Coos. And the category "Kid Calls" includes all juvenile vocalizations.

Because of the proximity of recording equipment to caged animals in sites A, B, C, and D, microphone and recorder were attached to a stand or tripod and left in the site after setup testing. No one entered the site until recording ended. In the large corrals, sites E and F, researchers were able to unobtrusively operate recording equipment from observation platforms attached to the sides of each corral. Recordings were continuous for durations that varied depending on availability of site access. Recording durations by site were: A = 89.10 min; B = 73.82 min; C = 71.30 min; D = 70.62 min; E = 88.62 min; F = 70.13 min. Effects of differences in durations were taken into account in analyses.

RESULTS

Occurrences of acoustical events as a function of time are shown for each site in Figures 1 to 6. Each figure provides a graphical record of events covaring in time over the entire duration of the acoustical recording in one site. On inspection, the records of events (plotted as successive 10-second aggregates for each category of vocal call and movement-generated noise) appear to differ both in magnitude of output and in degree of temporal relatedness. These differences appear to vary across sites. Variations in magnitude and temporal relatedness of calls within and across sites were examined by statistical and correlational analyses .

It may be seen in Figures 1 to 6 that records for sites A, E, and F (outdoor sites) each contain calls emitted by juveniles ("Kid Calls") while records for sites B, C, and D (indoor sites) do not. Consequently, this category of acoustical events was removed from the records of A, E, and F in order to equate event categories across sites prior to statistical comparisons.

Differences in Magnitude

Because an event record consists of a continuous succession of momentary occurrences, the number of events within time intervals that are small relative to the rate of occurrence may not exceed one count. Magnitude of occurrence, therefore, implies summation of events over some time interval. The aggregation interval selected for comparisons was 30 seconds (a rationale for this choice is given in the section on Temporal Correlation). An event magnitude is thus the number of instances of a given event within each

successive 30-second interval over the total duration of the acoustical record. The number of such intervals was treated as the number of samples. Because record durations differed somewhat across sites (refer to the Procedure section for durations), statistical analyses were based on samples that differed in size from site to site, i.e., an unbalanced factorial design. Rather than weighted mean, or harmonic mean, adjustments for unbalanced design, least squares ANOVAs were used to obtain maximum likelyhood estimates of effects.

Univariate and multivariate ANOVAs were computed for overall effects across event categories and sites. Events within sites were treated as repeated measures resulting in a mixed design. The results are summarized in Table I below. They indicate signifcant ($p < .01$) variance in the magnitudes of acoustical events associated with event type, site, and the interaction of event type with site. The significant interaction implies that relationships among magnitudes of the seven types of acoustical events changes across sites.

Table I

					Between
Source	***SS***	***df***	***MS***	***F***	***p***
Sites	1739.90	5	347.98	11.81	0.000
Error	26953.27	915	29.46		
Within					
Source	***SS***	***df***	***MS***	***F***	***p***
Events	5688.80	6	948.13	60.07	0.000
Events*Sites	8560.69	30	285.36	18.08	0.000
Error	86652.19	5490	15.78		

Site effects were examined by collapsing magnitudes across all event categories and comparing differences between site pairs by independent *t*-tests. Of the 15 pairs, mean differences between magnitudes in 10 sites were found to be significant ($p < .01$; *df* ranged between 138 and 172). Magnitudes in sites B and C exceeded those in every other site, except each other. B and C were found to not differ significantly.

Effects associated with event type were examined by collapsing magnitudes of event occurrence across all sites and comparing differences between event pairs by dependent *t*-tests. Pairwise comparisons of mean event magnitudes found all but four to differ reliably ($p < .01$; $df = 920$). The four pairs of event categories that were not significantly different were Coo *vs* GruffBark, EchoicBark *vs* ShrillCry, GruffBark *vs* Scream, and LowBark *vs* Noise. It may be noted that this finding does not imply that no differences exist between the temporal patterns of occurrence of these events. Differences in temporal patterns are readily apparent in Figures 1-6. Rather, it may be taken as evidence that the long-term emmission rates, averaged across sites, of these events are about the same, as shown in Figure 7 (open squares with error bars represent means and standard error of mean variation across sites). Over all sites, EchoicBarks and ShrillCrys were emitted at the lowest rates of about 1.6/min and 1.5/min. Coos, GruffBarks, and Screams were emitted at intermediate rates of about 3.1/min, 3.5/min, and 4.0/min, respectively. LowBarks and movement-generated Noise bursts occurred at highest average rates of about 6.3/min and 6.6/min.

The above comparisons do not reveal the site-to-site variations of magnitudes within event categories implicit in the significant overal event-by-site interaction. This was examined by pairwise comparisons of the six sets

of magitudes for each event category, e.g., magnitudes of occurrence of Coos in site A *vs* site B, in site A *vs* site C, etc. There were 15 comparisons of magnitudes within each event category (dependent *t*-tests; *df* ranged between 138 and 172). The number of significantly different ($p < .01$) pairs for each event category were: 9 Coo pairs, 5 EchoicBark pairs, 5 LowBark pairs, 0 GruffBark pairs, 0 ShrillCry pairs, 8 Scream pairs, and 10 HighNoise pairs.

Magitude of Coos in site C significantly exceeded Coos in all other sites while Coo magnitude in site D was significantly less than Coos in all other sites. EchoicBarks in site B were significantly greater than in any other site. LowBarks in site D were significantly less than in all other sites. Neither GruffBarks nor ShrillCrys were not significantly different in any pair of sites. Significantly fewer Screams occurred in sites D and C than in any others; magnitudes of Screams in sites D and C were not significantly different. Occurrences of HighNoise were significantly greater in every indoor site (B, C, D) than in every outdoor site (A, E, F); in every caged site (A, B, C, D) than in corrals (E, F). These differences are apparent in Figure 8 which shows magnitude means and standard errors for each event in each of the six sites.

The relationships illustrated in Figure 8 suggest that magnitudes in outdoor sites are generally lower than magnitudes in indoor sites. A test of this difference proved significant ($t(147) = 3.992$; $p < .01$). A major contributor to this difference appears to have been the considerably higher levels of movement-generated noise within indoor sites. With noise records removed, a test of the overall difference in magnitudes of call occurrence between indoor and outdoor sites was found to be not significant ($t(147) = 1.228$; $p = .22$).

Temporal Correlation

The degree to which the different categories of acoustical events covary over time was examined by pairwise cross-correlation of the event records shown in Figures 1-6. Each event stream was divided into 30-second time intervals, lag time between streams of events was set at 0, and correlations expressed as normalized coefficients of range -1 to 1. The rationale for selection of a 30-second time interval as the aggregate unit for cross-correlation was as follows.

The likelyhood of two irregularly occuring events being counted as coincident depends on their rates of occurrence and the width of the time interval in which they both must occur. Coincidence becomes more likely as width of the time interval increases relative to the rates of occurrence. Consequently, correlations across time intervals that are small relative to the rates of irregular events tend to be low. Increasing the interval width may yield a larger cross-correlation between two streams of events, depending on their distributions in time, but coincidence within wide intervals may not be behaviorally meaningful.

To establish an empirical basis for selecting an appropriate coincidence interval, cross-correlations were computed for a range of intervals between 1 and 60 seconds on all pairs of event streams recorded in site A. The resulting functions (correlation coefficient vs time interval) tended toward asymtotic values (positive and negative) at time intervals between 10 and 30 seconds. A time interval of 30 seconds thus appeared to yield stable correlations while probably not exceeding a reasonable limit on the temporal proximity of behavioral events considered to be coincident.

Event-pair cross-correlation coefficients are tabulated in Appendix II

for each site (A - F) and for event-streams collapsed across sites (column labeled ALL). Coefficients of 0.122 and 0.172 were significant at confidence levels of $p = .05$ and $p = .01$, respectively. Strength of temporal association between most pairs of events varied widely from site to site. For example, Coo-EchoicBark correlations ranged from 0.45 in site B to -0.04 in site F. By contrast, a few call pairs (e.g., LowBark-GruffBark, GruffBark-Scream, ShrillCry-Scream) were significantly positively related across all sites; the Coo-LowBark pair was significantly positively related in all sites except D. And several call pairs (Coo-GruffBark, EchoicBark-ShrillCry, GruffBark-ShrillCry) tended to positively covary in caged sites, but not in corrals.

The data also suggest differences in indoor *vs* outdoor trends. In Figure 9, cubic spline functions fit to coefficient averages tend to follow roughly the same trend for both indoor and outdoor sites, but diverge systematically over about three quarters of event-pairs. Divergences on the order of one standard error all show larger (more positive) average correlations for indoor sites. For comparison, averages for all sites are shown as points with vertical bars representing one standard error of the mean.

APPENDIX I

Vocal Repertoire of Adult *Macaca mulatta*

1. ***Low Bark***. These relatively quiet, low-pitched vocalizations are emitted by females and males when group behavior appears to be relatively stable, but with some small potential for danger, or conflict. In this context, *low barks* often are produced by only one individual at a time in a group, without apparent focus, possibly serving as acoustic markers of the caller's location and condition of mild arousal. Slightly more intense *low barks* that are focused toward a specific source of arousal, e.g., an intruder or an aggressor against a coalition member, may be emitted by one or more individuals. The low pitch and flutter-like quality of this call results from both its spectral and pulsatile structure. *Low barks* are composed of 2-5 pulses (mean 3.2) each and the pulses are generated at audible rates between 16 and 24 pps (mean 19.4 pps). Individual pulse durations vary between 31 and 54 msec (mean 45 msec). The effect is a low guttural flutter. Low pitch is reinforced by pulse spectral composition; energy is primarily concentrated in two bands, one very low band below about 890 Hz on average and one intermediate band that averages between about 2.5 and 5.9 kHz. Excited callers may expand this band to frequencies as high as 10 kHz. Conversely, the call may be emitted with energy no higher than about 4 kHz. Call durations also appear to covary with intensity, ranging between brief low level calls of about 84 msec and more intense calls of about 265 msec (mean 166.6 msec).

Rate and intensity of vocalization appear to reflect the caller's arousal level and whether the call is specifically directed or not. *Low Barks*

may be directed as mild threats toward a particular recipient, or generally broadcast without specific focus. Under apparently mild arousal conditions (e.g., group foraging on ground), *low barks* may be emitted non-directionally in clusters of several calls each with variable silent periods intervening between clusters. In this context, the non-directed *low bark* may signal proximity or spacing and may contribute to maintenance of group cohesion.

In the case of *low barks* directed toward a specific recipient, these calls may be produced at sustained rates of 2 or 3 per second over periods of several minutes by an individual responding focally to the presence of a non-aggressing intruder. Effectively, the calls mark the continued presence of the intruder and may act as group alerting, or warning, signals.. If the caller is suddenly further aroused by aggressive action of the intruder, *low barks* are likely to be replaced by either *threat barks* or *alarm barks*, depending on characteristics of the intruder (e.g., size, sex, rank, group membership, etc.) and the caller's resulting emotional valence (anger-defense *vs* fear-flight). If the caller is attacked, its vocalizations are likely to become *screams*.

2. ***Gruff Bark***: More intense and temporally compact than *low barks*, these low-pitched, harsh vocalizations are emitted while facing toward the focus of aggression. At their lowest levels *gruff barks* exceed *low barks* in intensity by 10 to 15 dB and the intensities at which *gruff barks* are produced may be varied by as much as 30 dB, a relatively large dynamic range for one type of call. At lowest levels, *gruff barks* may be emitted singly, or at irregular intervals, and may serve as a prelude to imminent physical aggression, especially when head-bobbing, piloerection, and tail elevation are evident in

the threatening animal. The more intense *gruff barks* tend to be emitted at rates averaging between about 3 and 5 calls per second and are nearly always associated with physical attack by the caller. Conflicts between adults frequently involve simultaneous production of aggressive *gruff barks* and defensive (or, possibly submissive) *screams* alternating with aid-soliciting *shrill cries*.

The *gruff bark* is a simple, but acoustically distinctive, variation of the *low bark*. The slow pulses of the *low bark* are temporally fused into continuous bands of energy, one band below about 700 Hz on average, and a second broad band which averages between about 2.5 and 13 kHz. This spectral structure differs from that of the *low bark* primarily in the greater average width of the mid-frequency band, a result simply of the greater average intensity of threat calls; spectra of *gruff barks* emitted at low intensities match pulse spectra of the more intense *low barks*.

Durations of *gruff barks* average about 157 msec. This is about the same as the average of the distribution of *low bark* durations, but there is significantly less variability in the durations of *gruff barks* than *low barks* (standard deviations of 32 and 59 msec, respectively). The amplitude pattern of *gruff barks*, though variable, tends toward sharp rise times followed by slower decays; rise times average about 38 msec (range 21-75 msec), less than a third of the call duration. This asymmetrical onset/offset pattern of relatively stable duration probably reflects vocal limits in the production of high intensity calls.

3. ***Echoic Bark***: Most acoustically intricate of rhesus atonal calls, the structure of *echoic barks* appears to mimic reflected sounds. These intense

calls seem to reverberate through the canopy as if reflected by distant and scattered surfaces, perhaps creating an illusion of calls originating from multiple locations and distances greater than actually exist. The effect might be acoustic camouflage, i.e., disguise of acoustic cues to the caller's spatial location, a particularly advantageous feature for a call that signals alarm.

The echoic semblance of this call is probably due to amplitude differences and time intervals between sharply-onset pulses. The call contains several pulses emitted in close succession at increasing amplitudes. The first pulses (usually two) are brief (mean 36 msec; range 12-42 msec) and precede a more intense pulse of longer duration (mean 71 msec; range 33-101 msec). In many calls, this main pulse offsets directly into a less intense band of noise of about the same duration (mean 88 msec; range 58-143 msec) which effectively extends the main pulse of the bark, but at a lower energetic level. Durations of *echoic barks* (mean 199 msec; range 138-321 msec) exceed on average durations of *low* and *gruff barks*.

Intervals between successive pulses of *echoic barks* are approximately the same, averaging about 28 msec. If these intervals actually were reverberation times, they would correspond to increases in propagation distances of about 32 ft between first and second pulses, and twice this distance between first and third (main) pulses. Unlike the slow and audible pulse rates in *low barks*, pulse rates in *echoic barks* (mean 37 pps; range 34-43 pps) are auditorially fused, but not temporally fused 13-13
as in *gruff barks*. Fusion of temporally delayed segments in *echoic barks* would contribute to the perception of spatial displacement of these calls. The illusion of reverberation might be reinforced by the substantial increments in

pulse amplitudes (10 dB mean increment between first and second pulses; 14 dB mean increment between second and main pulses) and by the associated increments in upper limit of pulse bandwidths (first pulse 0.09-4.84 kHz; second pulse 0.16-13.62 kHz; main pulse 0.09-22.00 kHz; offset noise 1.3-16.3 kHz) which may be heard as an increasingly loud, rising pitch.

Echoic barks appear to function as alerting, or alarm, signals. They are emitted by males and females preparatory to, and during, escape from frightening and dangerous situations, e.g., approach of a potential predator. They seem to be emitted when the source of danger (rarely a conspecific) is within sight of the caller and they nearly always appear to be associated with escape movements. *Echoic barks* from one animal may excite other group members to orient toward the source of danger and to begin emitting the same call, especially if the group is arboreal. Animals on ground may take to the trees in response to *echoic barks* from the canopy and those in trees may move to higher branches, or the group may flee. Emission of these barks during flights on ground through vegetation appear to be infrequent.

Aroused individuals facing a moderately threatening potential predator may equivocate between aggressive displays and escape movements while alternately emitting *gruff* and *echoic barks*. If distance between the source of danger and the caller is abruptly shortened, equivocation gives way to escape and alarm signals. If the predator does not pursue and if escape succeeds in re-establishing a safe distance, the caller may again resume equivocating between aggression and escape.

4. ***Scream***: As its name may suggest, the scream is an atonal, noisy expulsion of acoustic energy over a broad band of frequencies. Elicited by threat of

aggression or actual attack, both the energy content and the spectral structure of *screams* appear to depend on the severity of the aggression. A threatening gesture received from a higher ranking individual may elicit low level *screams* from the recipient. If the gesture is followed by further aggression (lunging toward or chasing), the energy levels and spectral distributions of the ensuing *screams* expand. The defensive individual may emit a series of *screams* interspersed with *shrill cries* (and "looks" for coalitionary support), the number and intensity of its calls apparently depending on the effectiveness of its attempts to escape. If the aggression involves actual physical contact (e.g., slapping, biting), the defensive *scream* usually becomes a super intense acoustic *blast* directed toward the aggressor's face.

Screams may consist of single vocalizations, but usually they are composed of several successive bursts of broadband energy. Occasionally, *screams* may be preceded by *clicks*, perhaps warning of very high stress levels. Tonal *shrill cries* soliciting coalitionary support also are often associated with *screams*, either preceding or interspersed among them in series of calls. *Screams* usually are broadcast directly toward the antagonist while *shrill cries* appear to be emitted with the caller's head turned away, probably in the direction of animals who might provide aid. Alternatively, rather than serving as a counter-aggression, defensive expressions, screams might also signal some degree of submission.

The spectral structure of *screams* is built around a wide band (2 to 8 kHz bandwidth) of intense energy often displaying irregular frequency modulation within its more intense regions. The lower edge of the high energy band is in the region 2.4-3.2 kHz with little energy below about 1.7 kHz in moderate

level *screams*. As *scream* intensity increases, the width of the high energy band expands to higher frequencies (an increase in call intensity by 25 dB corresponds to an expansion in upper frequency of the band from about 5.4 kHz to about 10.6 kHz). Although the upper region of this band usually does not exceed about 12 kHz, lower level noise extends to beyond 22 kHz. In the most intense forms of this call, *blasts*, it appears that the high energy band expands to encompass the entire spectrum which is nearly flat to beyond 22 kHz.

Although the abruptness of *scream* onsets appears to increase as intensity increases (from about 93 to 26 msec), call duration is not correlated with intensity. Calls range in duration between 150 msec to 1.2 sec (mean 436 msec), the length of the *scream* seeming to depend on the severity and persistence of aggression. The nature of the attack also is evident in irregular patterns of amplitude modulation that may be present in calls from an animal experiencing sustained aggression from which it cannot immediately escape. In this case, individual *screams* may consist of 2-5 contiguous ragged pulses of energy. Times between successive *screams*, or *screams* and *shrill cries*, of animals under attack range between about 20-48 msec, a nearly continuous cacophony of intense sound. Such rapid sequences of calls may be difficult for human listeners to resolve without practice, especially if these calls are mixed with intense *gruff barks* from an aggressing animal.

5. ***Shrill Cry***. This piercing tonal call may be emitted as brief chirps or intensely warbling whistles by males or females soliciting coalitionary support while receiving threats or responding directly to physical aggression.

In addition to the apparent recruitment-of-aid function of the *shrill cry*, its intense and acoustically complex nature probably makes it an ideal signal for the transmission of location information, as well as the caller's individual identity and condition of distress. The tonal nature of *shrill cries* is due to the banded structure of their energy spectra which we usually hear as having pitch. Though adult *shrill cries* may occur independently of other calls, often they are emitted in conjunction with atonal *screams*. In these defensive (and/or submissive) sequences, it appears that the caller faces its aggressor as it *screams*, but looks away, probably toward supporters, as it *shrill cries*.

One of the more acoustically variable of the rhesus calls, the *shrill cry* exhibits complex modulation in both amplitude and frequency domains. Tight distributions of energy in narrow bands (range 0.2-3.0 kHz; mean 900 Hz) are spaced roughly at harmonic intervals that co-vary in center frequency and amplitude over the variable durations of the *shrill cry* giving this type vocal expression a sound quality that may range from brief, intense chirps to more protracted and sharply pitch-modulated whistle sounds.

Patterns of frequency modulation may involve combinations of such pitch-varying effects as abrupt up or down sweeps in bands, harmonic warbling, and variations in sharpness of tuning (width) of bands. The extent of frequency modulation in *shrill cries* exceeds that of other rhesus calls, ranging between 0.7 and 5.5 kHz (mean modulation range 3.1 kHz). Amplitude also may undergo appreciable modulation (e.g., 7-19 dB) during *shrill cry* emission depending apparently on momentary events to which the caller is reacting, as well as its arousal level. Irregular amplitude patterns composed of multiple pulses of different shapes and durations appear to be associated with high levels of distress.

Shrill cries usually contain at least three detectable energy bands separated by intervals of 1.4-5.2 kHz (mean 3.9 kHz). The lowest and most intense band tends to be in the range 1.6-7.7 kHz (mean 5.1 kHz) and averages 17 dB greater SPL than its first harmonic (it is probably this lowest band that determines the pitch heard by humans). The average difference in SPL between the first and second harmonic is only 4 dB, which appears to represent the rate at which the intensity of the higher harmonics declines. However, even if *shrill cries* contain more than the first three bands, some of the higher bands may be missing, or buried in noise. In the case of relatively intense calls, the upper range of the highest band may extend beyond 20 kHz.

6. ***Coo***: A clear, tonal call that is emitted at low-to-moderate intensities usually by several individuals in a group under conditions that appear to be behaviorally reinforcing, e.g., conditions involving either receipt of food or removal of threat. For example, sight of food and events anticipatory of food presentation elicit from a group in trees near a familiar feeding place a chorus of excited *coos*. Similarly, if withdrawal of a fear-inducing situation (aggressing intruder on the ground; monkeys in trees) results in cessation of alarm barking, group *coo*-calling tends to follow the apparent reduction of group anxiety. It is not inconsistent with this association between group *coo*-calling and reinforcing conditions to hear occasional isolated *coos* from single individuals in low states of arousal, e.g., while reclining on a shady limb in mid-afternoon heat.

General features of *coo* spectral and temporal structures are relative stable. Energy is distributed throughout the spectrum in very narrow bands (bandwidth: 100-200 Hz) at approximately regularly spaced intervals that range

between 400 and 900 Hz, depending on the frequency of the fundamental. However, one or more energy bands may be absent, or at undetectably low amplitudes, in the spectra of some calls. Bands usually are not found a frequencies above about 11 kHz.

The pattern of pitch variation in most *coos* is visible in the patterns of frequency modulation that spectral bands undergo. Pitch gradually climbs to about the midpoint of the call and then declines, the direction and range of modulation increasing towards the middle of the call. The range of frequency modulation of energy bands increases with frequency, though not with harmonic regularity. Modulation may be negligible in low frequency bands near the fundamental, as much as 700 Hz in mid spectrum bands, and approach 1.6 kHz in upper spectral bands. However, the pattern of frequency modulation in upper bands often is not present in lower bands, and upper band structure may vary in calls successively emitted by the same animal. These differential vocal effects may constitute recognizable individual differences or possibly contextually significant information. In any case, we have firm evidence that individuals may alter the upper spectral structure of successively emitted *coos*. Spectral structure is not fixed.

Call durations, relative amplitudes, and amplitude patterns appear to covary and may be related to differences in general features of social contexts. Although the range of relative amplitudes of *coos* appears narrow (4-6 dB) in comparison to other calls, amplitudes of calls produced by excited animals in anticipation of food tend to be greater than those produced by animals relieved of tension. Likewise, while amplitude patterns of low level *coos* tend to be flat with gradual, symmetrical rise/decay times of about 64 msec and moderate durations (mean 192 msec), more intense *coos* exhibit sharper

rise times (about 45 msec) and longer durations (mean 328 msec). The apparent contextual dependency of these acoustic differences may not be valid if, indeed, the differences turn out to be reliable.

7. ***Click***: The briefest of rhesus vocalizations, this sound is a single, intense pulse ranging in duration from 12 to 40 msec (mean 26 msec). *Clicks* may be emitted singly or in irregularly distributed pulse trains at average rates of about 44 pps for several seconds at a time. Although most energy is concentrated in a band between about 2.6 and 12 kHz, the spectra of more intense *clicks* are relatively flat with energy extending to beyond 22 kHz. *Clicks* may occur independently of any other calls, or in conjunction with *screams* and *shrill cries*. The short durations and broad spectra of *clicks* would appear to make these sounds readily localizable, especially when emitted as pulse trains. It is possible that *clicks* signal a high level of arousal, perhaps predictive of likely aggressive or defensive reactions if arousal-inducing conditions persist. However, *click* pulse structure offers little room for individual variation and probably would not be a strong signal of caller identity.

8. ***Shrill Scream***: A mixture of *shrill cry* and *scream*. Acoustical characteristics of this call a those of intense *screams* overlaid by tight, irregularly modulated bands of energy typical of the *shrill cry*. The relatively greater intensity of the latter makes the this call appear as a more intense and noisy (less tonal) *shrill cry*. It appears to be emitted by highly aroused animals under attack with little opportunity for immediate escape. The *shrill scream* seems to simultaneously combine components of

defense (acoustic blasts) with piercing solicitations of aid.

While the acoustical properties of this call appear to be completely described by *screams* plus *shrill crys*, the *shrill scream* is not simply two calls produced independently then summed. Remarkably, it is a call produced as an integral output of a single vocal system.

APPENDIX II

Cross-Correlation Coefficients of Call Series

PAIRS	ALL	A	B	C	D	E	F
Coo/Echo	.06	-.05	.45	.24	-.03	-.03	-.04
Coo/Low	.49	.35	.33	.70	-.06	.45	.39
Coo/Gruff	.12	.39	.05	.25	.21	.00	-.01
Coo/Shrl	.05	.01	-.08	.43	.03	-.13	.03
Coo/Scrm	.00	-.10	-.12	.28	.11	-.13	.13
Coo/Kid		-.14				-.15	.00
Coo/N	.06	.17	-.09	.10	.14	-.02	.08
Echo/Low	.05	-.09	.11	.11	-.02	-.03	-.03
Echo/Gruff	.18	.05	.21	.04	.25	.60	-.02
Echo/Shrl	.05	.29	.17	.27	.18	.00	-.02
Echo/Scrm	.08	.29	-.07	.13	-.03	.43	-.03
Echo/Kid		-.06				-.02	-.01
Echo/N	.13	.04	.25	.30	.17	-.01	-.04
Low/Gruff	.36	.20	.41	.58	.57	.21	.24
Low/Shrl	.09	.16	-.04	.27	.32	-.06	.11
Low/Scrm	.08	-.02	.05	.23	.33	-.02	.20
Low/Kid		-.04				-.07	.28
Low/N	.11	-.09	.12	.15	.38	-.01	.03
Gruff/Shrl	.12	.18	.20	.14	.48	.01	.00
Gruff/Scrm	.26	.12	.26	.13	.58	.47	.17
Gruff/Kid		-.08				-.05	-.05
Gruff/N	.15	-.04	.29	.04	.50	-.03	.17
Shrl/Scrm	.48	.43	.50	.48	.55	.57	.44
Shrl/Kid		-.08				.26	.07
Shrl/N	.02	-.06	.27	.04	.15	-.01	-.09
Scrm/Kid		-.02				.36	.08
Scrm/N	.02	-.01	.10	.14	.26	.02	.11
Kid/N		-.12				.10	.04

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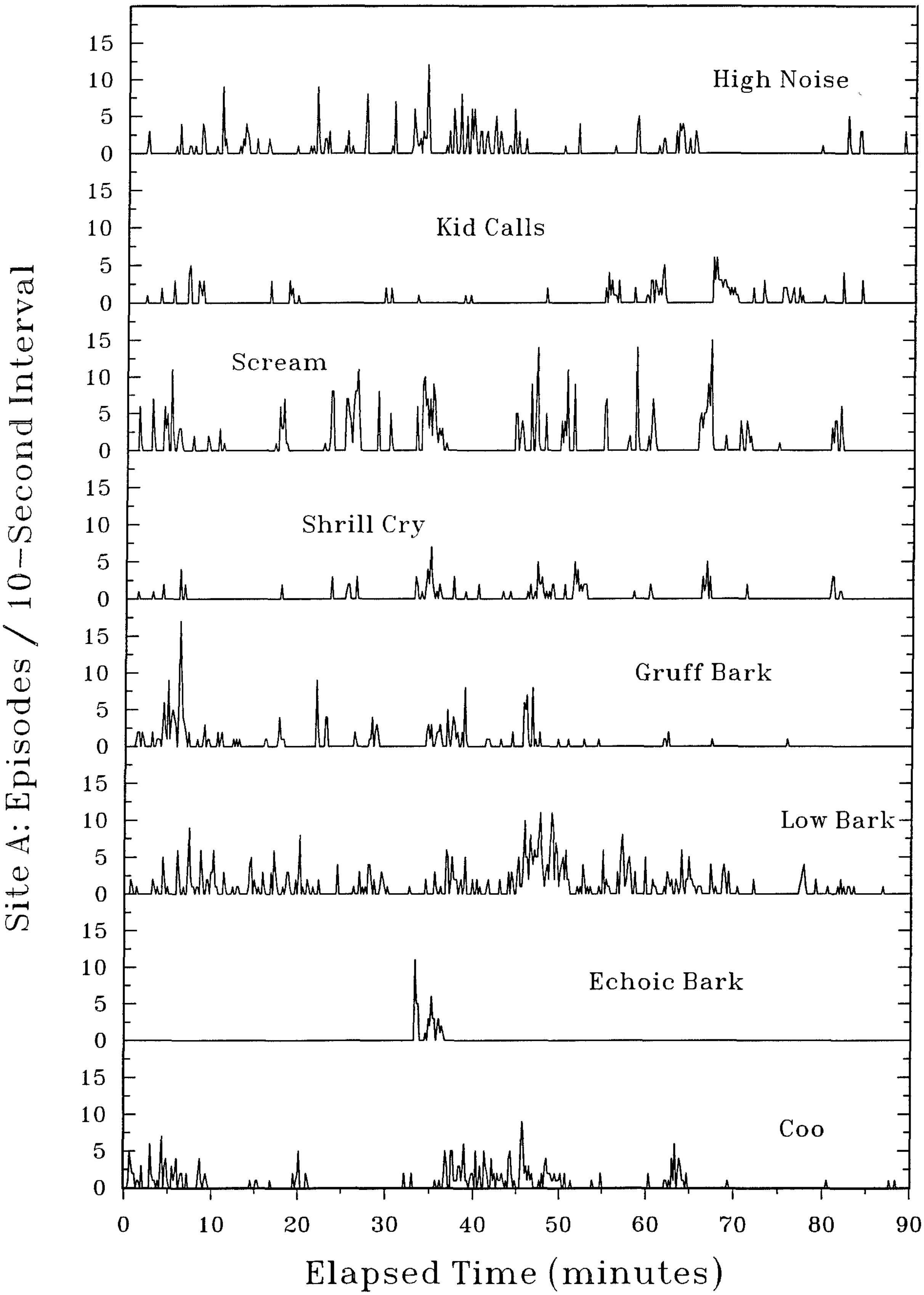


High Noise
Kid Calls
Scream
Shrill Cry
Gruff Bark
Low Bark
Echoic Bark
Coo
Site A: Episodes / 10-Second Interval
Elapsed Time (minutes)
0
10
20
30
40
50
60
70
80
90
0
5
10
15

Fig. 1

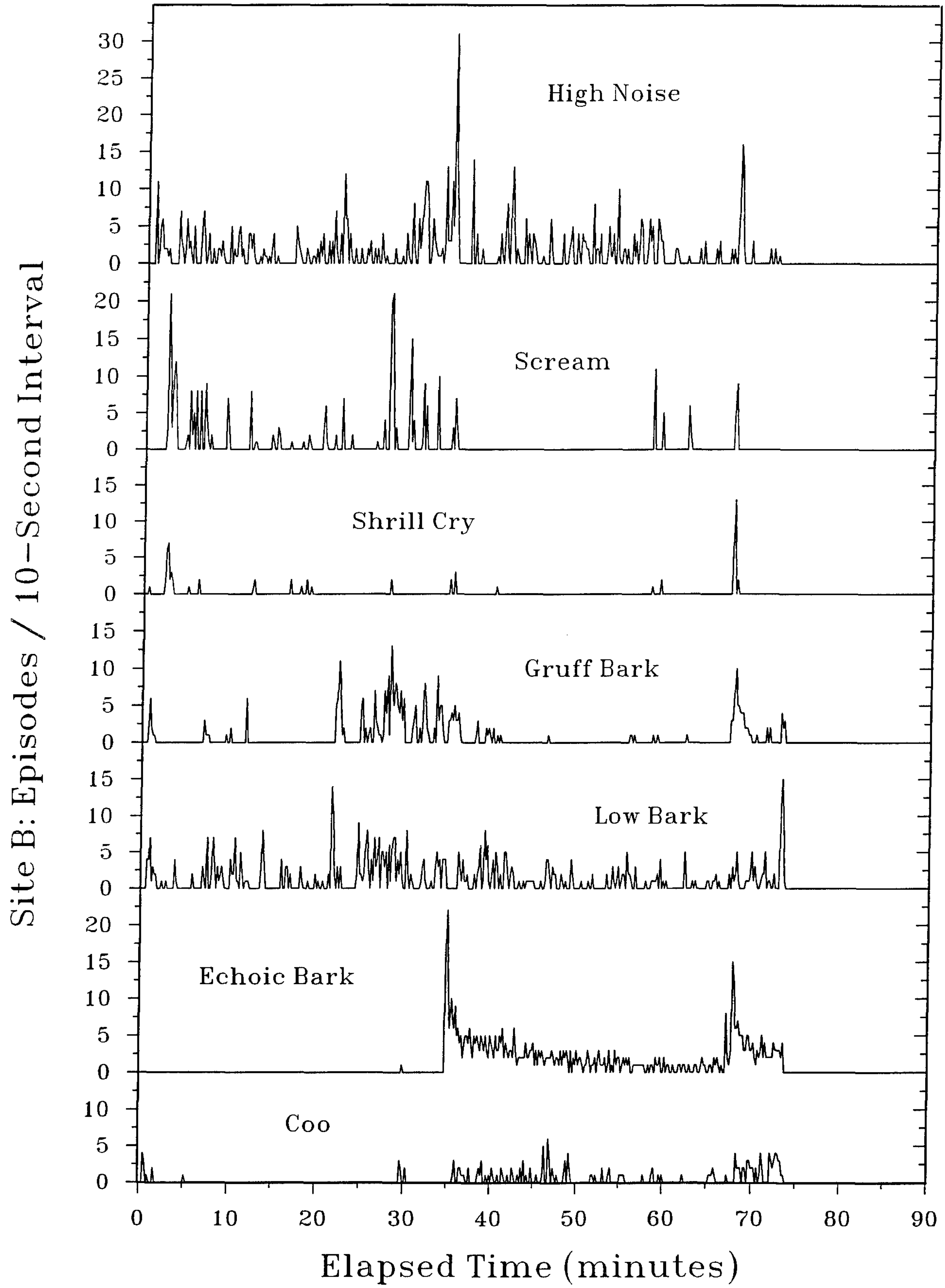
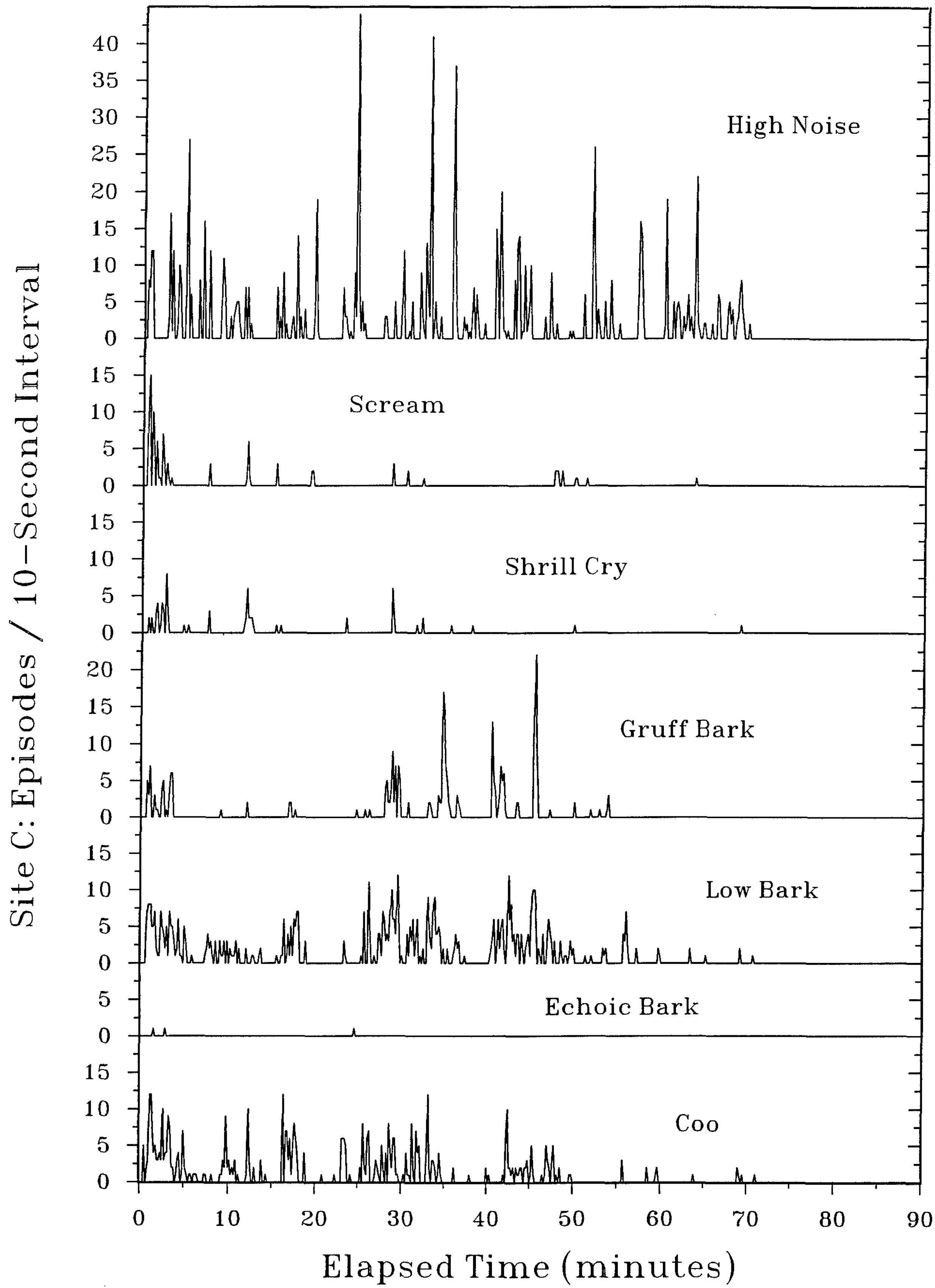

High Noise
Scream
Shrill Cry
Gruff Bark
Low Bark
Echoic Bark
Coo
Site B: Episodes / 10-Second Interval
Elapsed Time (minutes)
0
10
20
30
40
50
60
70
80
90

Fig. 7


High Noise
Scream
Shrill Cry
Gruff Bark
Low Bark
Echoic Bark
Coo
Site C: Episodes / 10-Second Interval
Elapsed Time (minutes)
0
10
20
30
40
50
60
70
80
90

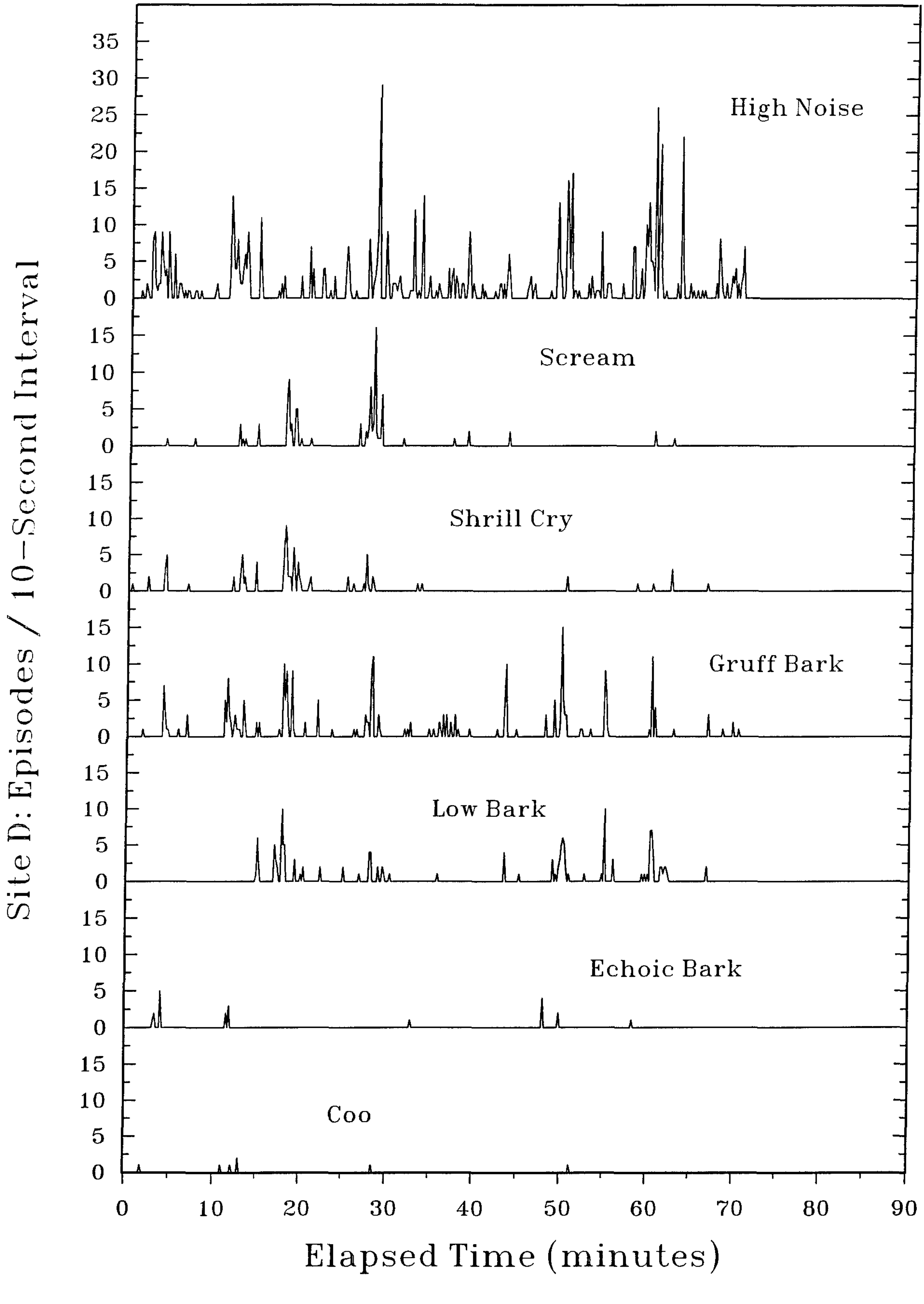
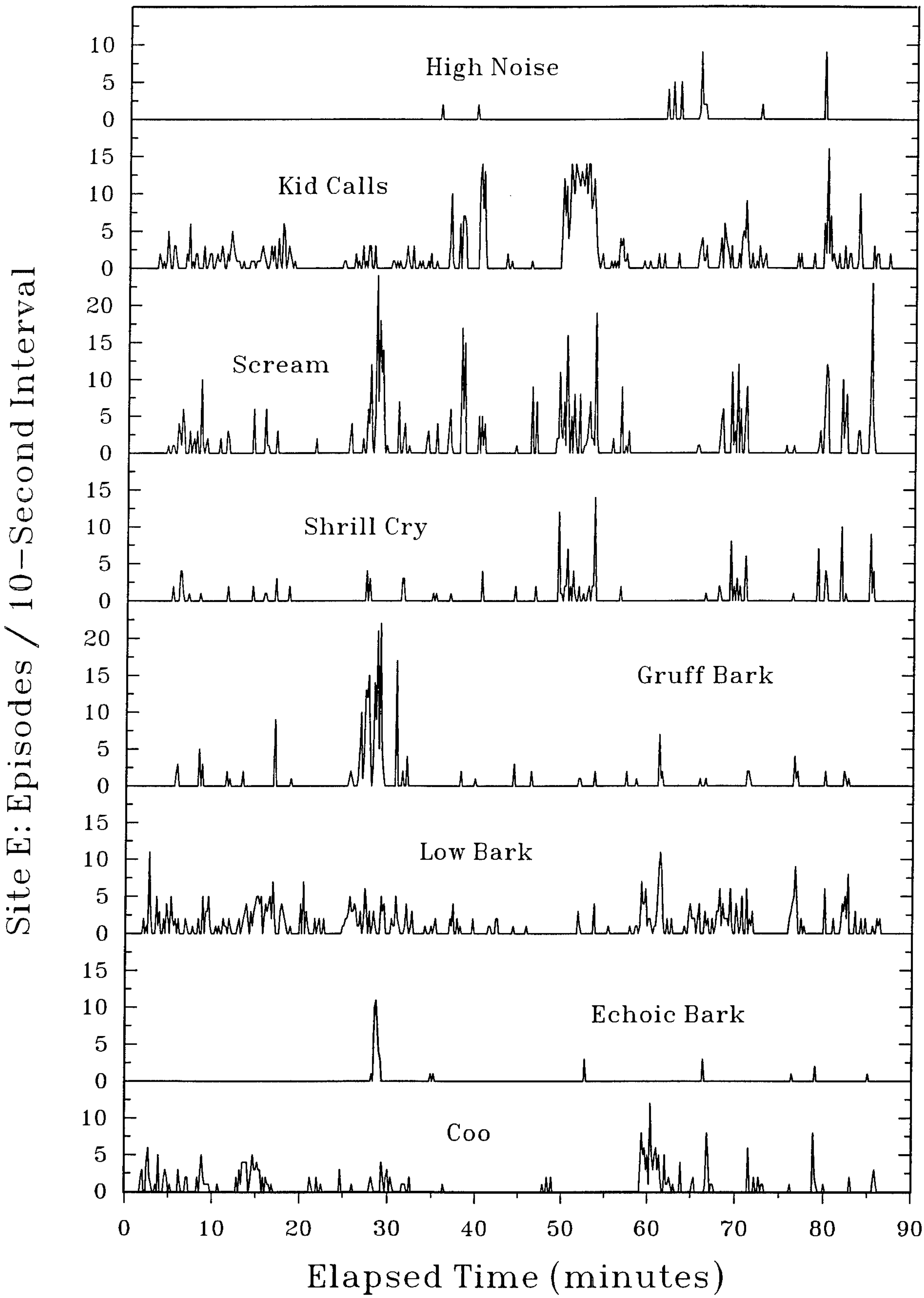

High Noise
Scream
Shrill Cry
Gruff Bark
Low Bark
Echoic Bark
Coo
Site D: Episodes / 10-Second Interval
Elapsed Time (minutes)
0
10
20
30
40
50
60
70
80
90

Fig. 4


High Noise
Kid Calls
Scream
Shrill Cry
Gruff Bark
Low Bark
Echoic Bark
Coo
Site E: Episodes / 10-Second Interval
Elapsed Time (minutes)
0
10
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30
40
50
60
70
80
90
0
5
10
15
20

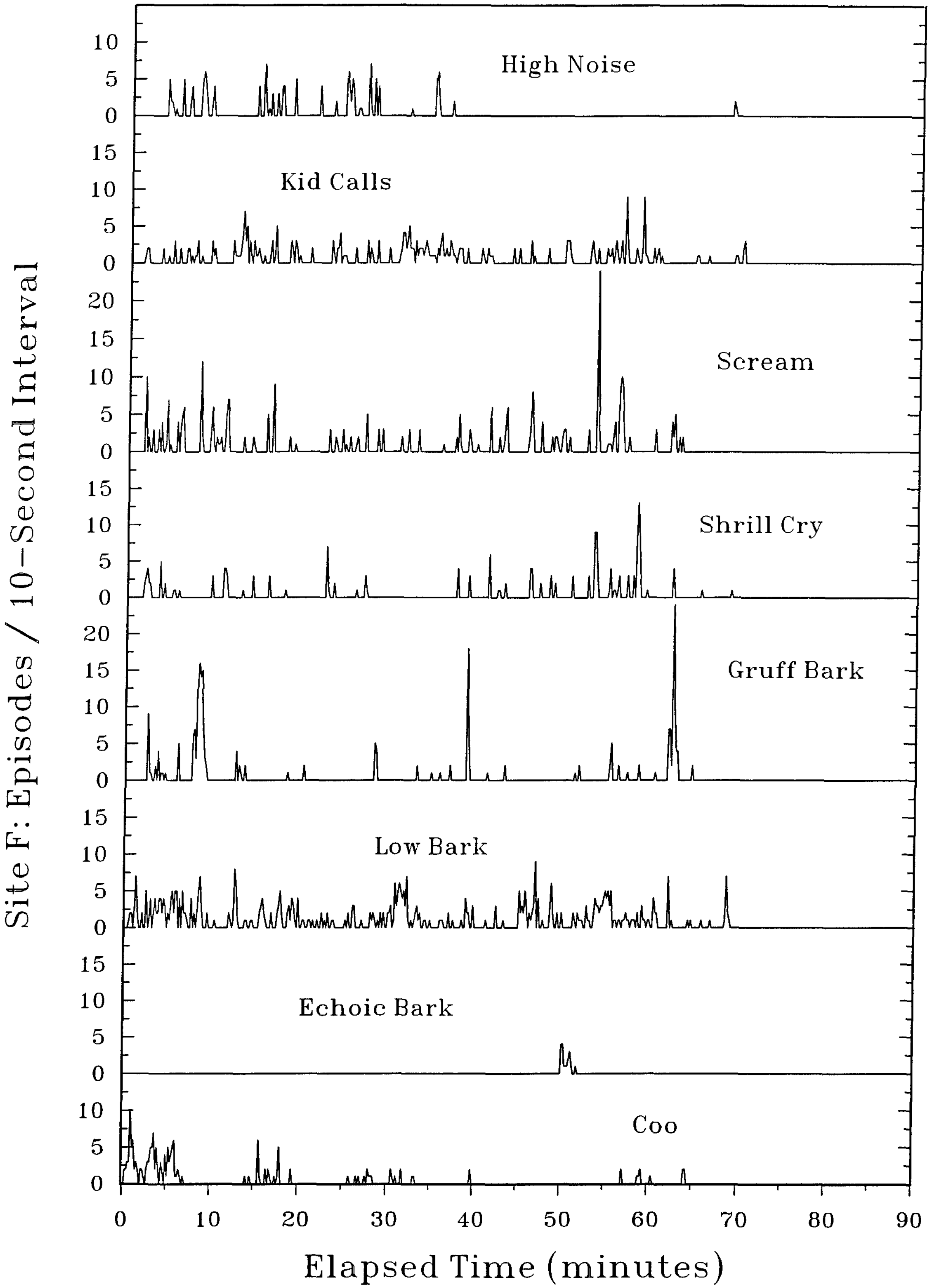
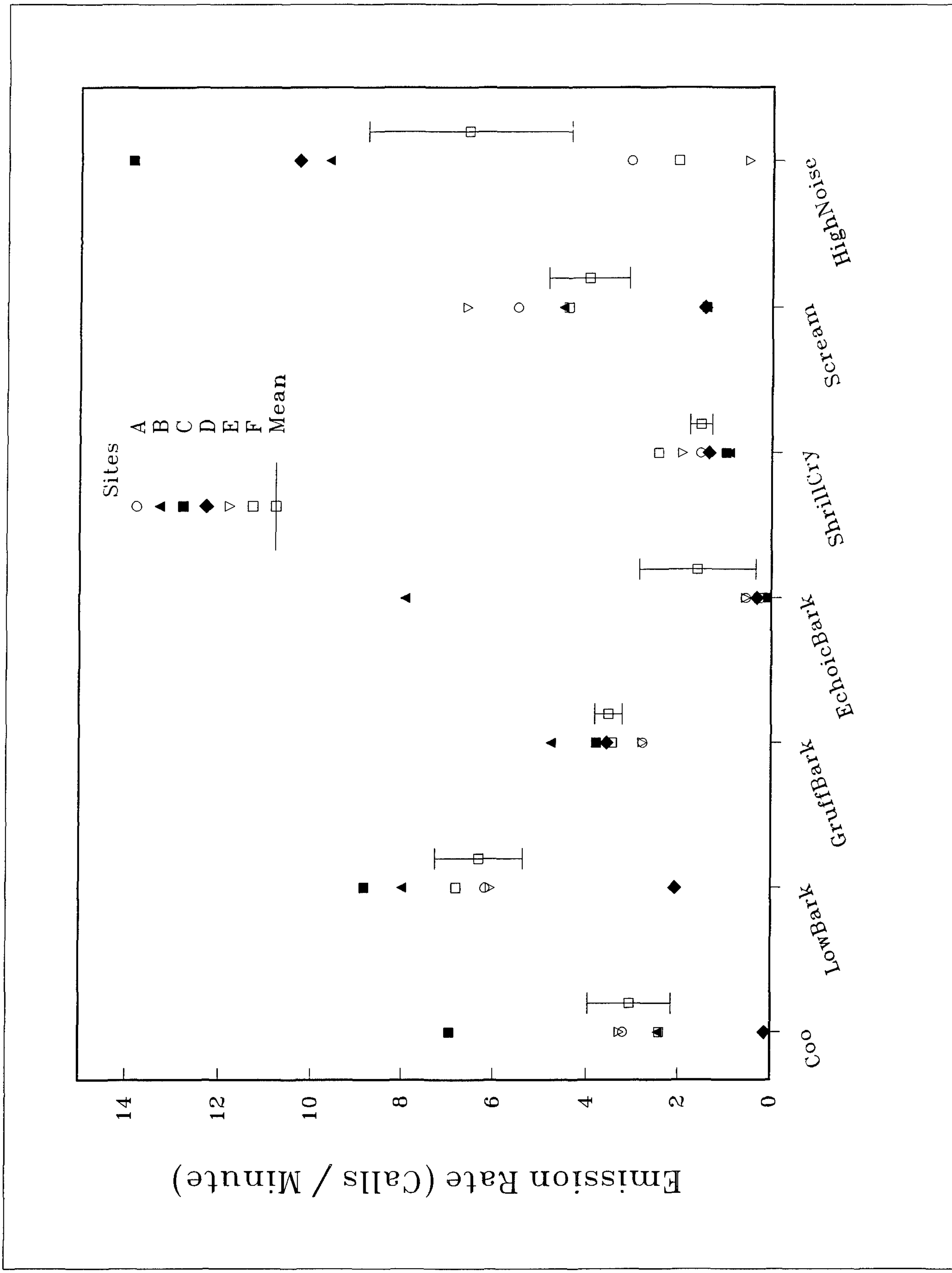
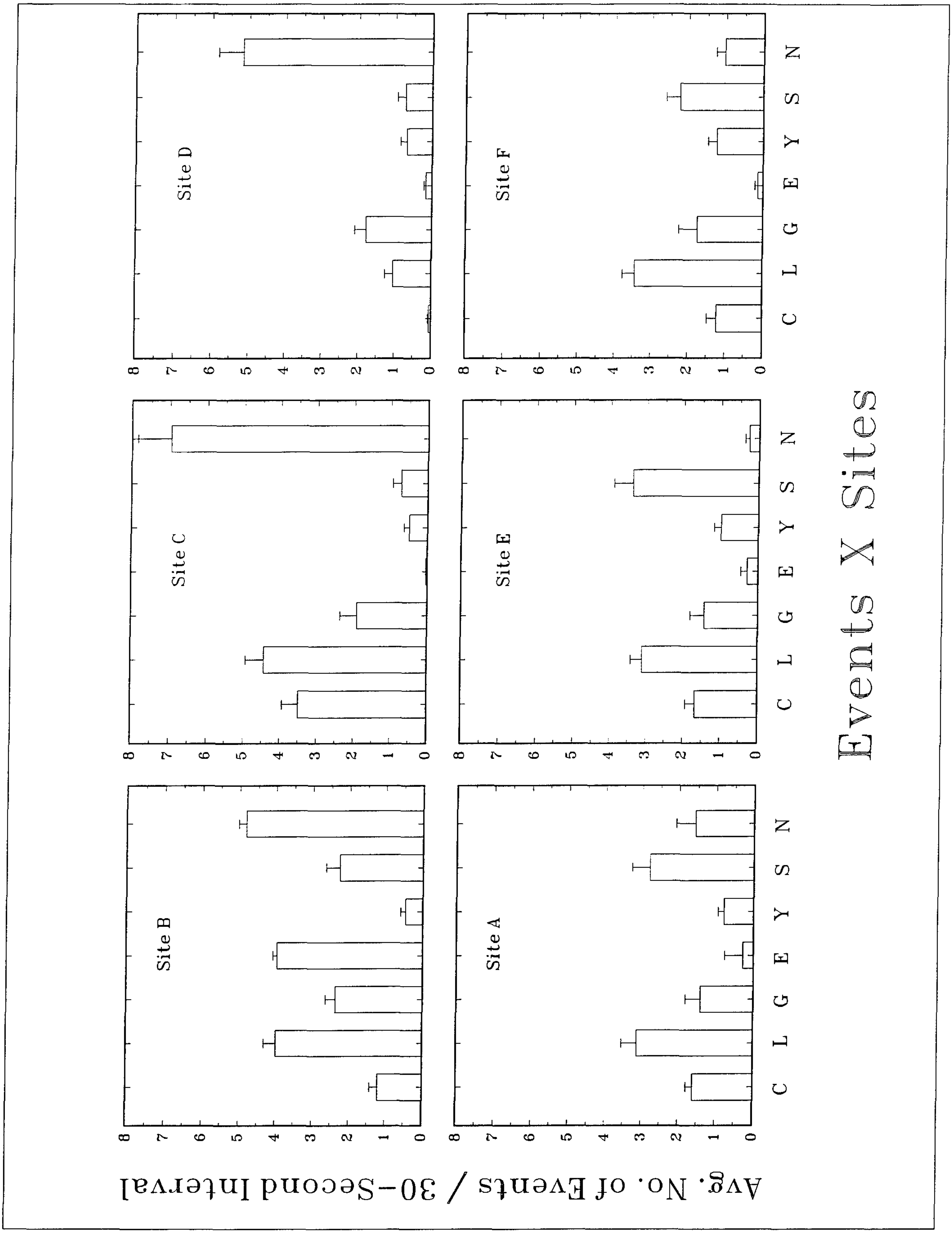

High Noise
Kid Calls
Scream
Shrill Cry
Gruff Bark
Low Bark
Echoic Bark
Coo
Site F: Episodes / 10-Second Interval
Elapsed Time (minutes)
0
10
20
30
40
50
60
70
80
90

Fig. 6

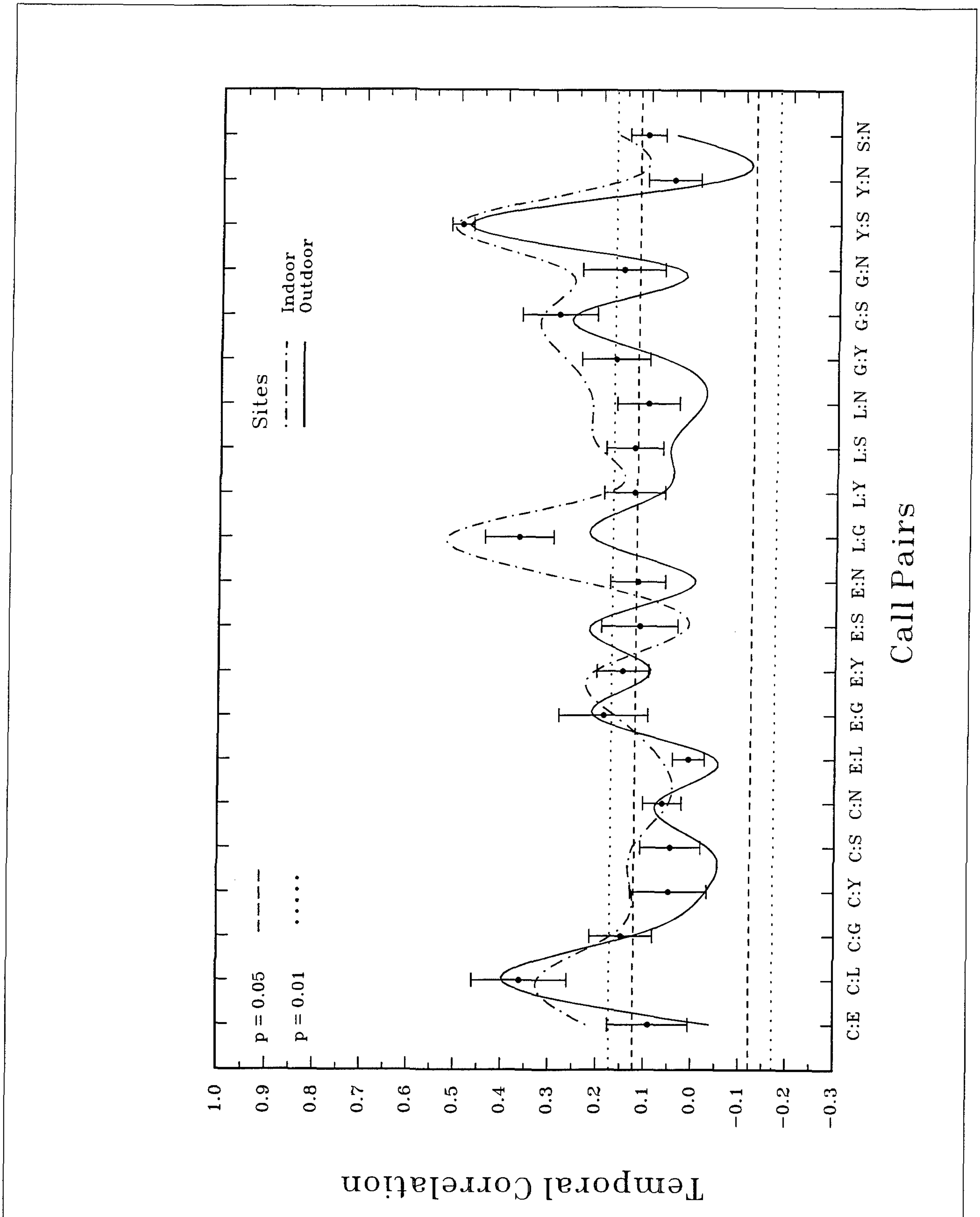


Emission Rate (Calls / Minute)
0
2
4
6
8
10
12
14
Coo
LowBark
GruffBark
EchoicBark
ShrillCry
Scream
HighNoise
Sites
A
B
C
D
E
F
Mean



Events X Sites
Avg. No. of Events / 30-Second Interval
Site A
Site B
Site C
Site D
Site E
Site F
C L G E Y S N
0 1 2 3 4 5 6 7 8

Fig. 6


Temporal Correlation
Call Pairs
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
C:E C:L C:G C:Y C:S C:N E:L E:G E:Y E:S E:N L:G L:Y L:S L:N G:Y G:S G:N Y:S Y:N S:N
p = 0.05
p = 0.01
Sites
Indoor
Outdoor

SIMULATION OF THE MOTION OF SINGLE AND LINKED ELLIPSOIDS

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Interim Report for:
Summer Research Extension Program

Sponsored by:
Air Force Office of Scientific Research
Bolling Air Force Base, Washington, D.C.
and
Wright State University

May 1994

SIMULATION OF THE MOTION OF SINGLE LINKED ELLIPSOIDS

David B. Reynolds
Associate Professor
Department of Biomedical and Human Factors Engineering
Wright State University

Interim Report

This study is attempting to simulate the motion of single ellipsoids and joined ellipsoids floating in water. The ellipsoids are representations of portions of the human body, such as the head and torso. The long range goal of the research is to be able to predict the motion of the entire body with attached personal flotation devices (PFD) both in calm water and in waves. Successful simulation of the latter will have an impact on improved design of PFD's.

To date, we have simulated some of the experimental results of the Institute for Marine Dynamics in Canada. We only have some of the preliminary data from this group and we expect to produce additional simulations of their data in the near future. The computer model we are working with, developed along with researchers at Armstrong Laboratory at WPAFB, appears to be suitable for simulating the experimental data being generated by the Canadian group. Furthermore, the model has the capability of being extended to simulate the motion of multiply-linked floating bodies.

DONALD ROBINSON'S REPORT NOT READY AT TIME OF PUBLICATION

A COMPARISON OF HEXAMETHYLENE DIISOCYANATE SAMPLING AND ANALYSIS METHODS

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Final Report for
Summer Research Extension Program
Armstrong Laboratory
Occupational and Environmental Health Directorate
Brooks Air Force Base
San Antonio Tx, 78235-5501

Sponsored by:
Air Force Office of Scientific Research
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and

Southwest Texas State University
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January, 1994

A COMPARISON OF HEXAMETHYLENE DIISOCYANATE SAMPLING AND ANALYSIS METHODS

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Abstract

Several methods were used for the analysis of 1,6-hexamethylene diisocyanate, HDI, monomer and oligomer. Samples were collected during several spray-painting operations, and two impinger collection methods were compared with each other as well as with methods which employ a fiber filter, sorbent or a total particulate collection approach.

The results demonstrate that the impinger collection methods, NIOSH Method 5521 and a new NIOSH method for Isocyanates, give higher results than those which employ a 1-(2-pyridyl)-piperazine-coated filter (OSHA Method 42) or a tryptamine-coated XAD-2 sorbent tube.

The results indicate that capillary zone electrophoresis may be used as an analytical tool for the separation of 1-(2-pyridyl)-piperazine-derivatized HDI, and may offer better resolution than HPLC when HDI is in a complicated polyurethane paint matrix.

The results from total particulate sampling indicate that the concentration of polyisocyanate in air may be estimated (within a factor of two) from the relative amount of hardener in the paint formulation.

Finally,the results demonstrate that the new NIOSH method for Isocyanates, gives higher results than those obtained using the old NIOSH Method 5521.

A COMPARISON OF HEXAMETHYLENE DIISOCYANATE SAMPLING AND ANALYSIS METHODS

Walter E. Rudzinski

Introduction

Workers who are involved in polyurethane spray-painting may experience adverse health effects which have been ascribed to the activator in the paint formulation. Hexamethylene diisocyanate or HDI is the most-commonly employed activator used in U.S. Air Force polyurethane spray paint operations and may be found either in the form of a monomer or as a polyisocyanate in the aerosol form.

HDI monomer because of its volatility and the reactivity of its NCO groups is an occupational hazard for which the American Council of Governmental Industrial Hygienists, ACGIH, has recommended a threshhold limit value (TLV) of 34 $\mu g/m^3$ (5 ppb) as an 8-hr time-weighted average, TWA(1). A TLV for the polyisocyanates of HDI, the biuret and the isocyanurate trimer, has not been established even though the polyisocyanates contain reactive isocyanate groups, and in an aerosol form may be inhaled during spray-painting operations(2,3).

Some early reports suggest that polyisocyanates can cause occupational asthma during spray-painting(4-6). The studies often do not differentiate between the adverse effects caused by diisocyanate monomer and polyisocyanate because of the presence of both in paint formulations. However, a recent report has demonstrated that prepolymers of HDI are unequivocally a cause of occupational asthma(7). For this reason, a permissable exposure limit (PEL) should be established not only for isocyanate monomer but for all isocyanates regardless of their chemical form, as has already been done in some countries(3,8) and in the state of Oregon(9).

The levels of HDI monomer and polyisocyanate oligomer during spray painting are significant. A ten year survey in the state of Oregon indicated that 6 % of all the air samples were higher than 0.02 ppm HDI monomer which is higher than the PEL established in the state of Oregon; while an even higher, 42%, of the samples exceeded the Oregon PEL of

1 mg/m^3 for HDI polyisocyanates[9]. There is a need therefore to ensure that methods used for the evaluation of isocyanate monomer and polyisocyanates in the workplace give accurate and reproducible results.

Currently most methods for the analysis of isocyanates have been developed for the monomer. In these methods the sample is collected with either an impinger or filter, derivatized, then separated using high performance liquid chromatography, HPLC, with either ultraviolet absorbance (uv), fluorescent(fluor) or electro- chemical (ec) detection. The entire area has been the subject of various reviews[10-12].

In an effort to devise simpler sampling and analysis procedures for both the monomer and the polyisocyanates we have compared and in some cases modified four different methods for the determination of HDI:

1. NIOSH Method 5521[13] which uses an impinger filled with 1-(2-methoxy phenyl)-piperazine in toluene for collection and derivitization of the sample. The analyte is then separated using HPLC with simultaneous uv and ec detection. This method is the best available method for HDI polyisocyanates and has been used as a "benchmark" for developing new methodologies.
2. A new, draft NIOSH Method: Isocyanates[14] which uses an impinger filled with tryptamine in DMSO for the collection and derivitization of diisocyanate monomer and oligomers, HPLC separation, and simultaneous fluorescence and ec detection. The method has been compared with NIOSH Method 5521 as well as extended to include sampling with a tryptamine-coated XAD-2 resin.
3. OSHA Method 42[16] which involves the collection of sample by drawing air through a fiber filter coated with 1-(2-pyridyl)-piperazine. The derivatized isocyanate is then analyzed by using HPLC. The method has been compared with NIOSH 5521 in order to see whether filter sampling can provide results comparable to those obtained using an impinger. The analytical procedure has also been modified to see whether capillary zone electrophoresis offers any advantages for the separation and analysis of HDI monomer.
4. NIOSH Method 0500[17] which involves the collection of total particulates by drawing air through preweighed filters. The method has been

used to determine polyisocyanate based on the total mass of particulates and the relative weight percent of polyisocyanate in the original paint formulation.

Experimental

Reagents

1-(2-methoxyphenyl) piperazine (MOPIP) from Fluka; 3-(2-aminoethyl) indole (tryptamine) from Sigma.1-(2-pyridyl)piperazine (PPIP) and 98% pure HDI monomer were obtained from Aldrich Chemical Co. (Milwaukee, Wis.). Desmodur N-75 which is 35-40% biuret trimer of HDI and 35% polyisocyanate in xylene (MSDS data sheet) was obtained from Miles Chemical Co. (Pittsburgh, PA).The hardener used for preparing tryptamine-derivatized polyisocyanate standards was obtained from Deft (Irvine,CA) and contained 60% aliphatic diisocyanate and 40% organic solvents. XAD-2 was purchased from Supelco (Bellefontane, PA). All other chemicals and solvents were reagent grade or better.

PPIP, MOPIP and tryptamine were used as derivatizing agents in preparing HDI urea standards as described in OSHA Method 42[16], NIOSH Method 5521[13] and NIOSH Method: Isocyanates[14] respectively. MOPIP-derivatized polyisocyanate standards were prepared from Desmodur N-75 according to NIOSH Method 5521. Tryptamine-derivatized polyisocyanate standards were prepared according to NIOSH Method: Isocyanates from the Deft hardener.

Sampling Apparatus

Constant-flow personal air-sampling pumps capable of drawing up to 2.0 L/min., and standard midget impingers filled with MOPIP or tryptamine solutions were used to collect samples according to NIOSH Method 5521 and NIOSH Method:Isocyanates protocols. Solid sorbent tubes (5 mm i.d.) were filled up to a height of 3 cm with tryptamine coated on XAD-2 resin (0.1% w/w)[15,18] Glass fiber filters were coated with 2.0 mg of 1-(2-pyridyl) piperazine) and then mounted in 37 mm cassettes.Air samples were collected open-faced at a flow rate of 1.0 L/min. Total particulates were collected open-faced according to NIOSH Method 0500[17] at a flow rate of 2.0 L/min.

Instrumentation

The HPLC system consisted of a Hewlett-Packard Series 1090 chromatograph with autosampler, and diode array uv-vis absorbance detector. A Hewlett-Packard 1049A electrochemical detector operated in the amperometric mode at +0.8 V was used to detect the MOPIP and tryptamine derivatives. An ABI 90 fluorescence detector operating at an excitation wavelength of 275 nm was used to detect the tryptamine derivatives. The fluorescence detector was not equipped with a monochromator to limit the bandpass of the emission and no filters were used, and therefore the emission intensity was detected over the entire range,190-700 nm, of the instrument.

The columns used were either Hypersil ODS 5μ (NIOSH Method 5521) or LiChrospher 100 RP 18 5μ (OSHA Method 42 and NIOSH Method:Isocyanates). The mobile phases were those specified in NIOSH Method 5521, NIOSH Method Isocyanates or OSHA Method 42. In the analysis of polyisocyanate, the mobile phase was sometimes adjusted to a higher concentration of organic modifier in order to shorten the retention time.

Hewlett-Packard 3396 series II integrators were used to quantitate the chromatographic peaks. The concentration of HDI monomer was determined by comparing the integrated area with that of authentic standards. The concentration of polyisocyanate was determined by comparing either the area of the largest peak (attributable to biuret trimer) or the total area under the three largest peaks in the chromatogram with that of a series of standards.

A Waters Quanta 4000 CZE system equipped with a Waters 730 data module was used to analyze for HDI. All samples were injected using hydrostatic injection for 8 sec. The height differential of the reservoirs was 9.8 cm. The capillary column had an effective separation length of 50.3 cm and an inner diameter of 75 μm. The total column length was 57.8 cm. The operating voltage was set at 20 kV. Either 0.1 M sodium acetate or 0.01 M sodium phosphate buffers adjusted to a pH of 3.0 were employed. The background current through the capillary was 75 μA when using 0.01 M phosphate buffer. The detector wavelegth was set at 254 nm. The column was reconditioned daily with 0.5 M NaOH, and the capillary was purged with buffer for 2 minutes between each analysis.

Field Study 1, Keesler AFB

Six different spray paint operations were evaluated. Operations 1 and 4 involved spray-painting of a truck and trencher respectively in a paint booth. Operations 2, 3, 5 and 6 involved spray-painting wheels, signs, a generator and aircraft wing parts respectively. High volume low pressure (HVLP) spray guns were used throughout. Area samples and personal samples were collected in the area of overspray and in the breathing zone respectively. Area samplers were 3-4 ft above the floor and about 2-5 feet downdraft from the equipment being painted.

Two different Deft polyurethane paint formulation were used. Both formulations contained pigment: hardener in a 1:1 ratio.

Field Study 2, Tinker AFB

A B-52 bomber was spray painted. Six hours were spent painting the aircraft, and the remaining two, cleaning the Kraco Pro AA 4000 electrostatic paint guns. Four personal samples were collected. Two of these were in the breathing zone of the manlift operator, while the other two were in the breathing zone of two spray painters. The four area samplers were positioned on the east and west sides of the hanger dock approximately 15 feet from the wing tips of the aircraft.
All sampling was performed using tryptamine-coated XAD-2 sorbent tubes which were positioned next to impingers filled with tryptamine in DMSO.

A Deft polyurethane paint formulation was used which contained pigment: hardener in a 3:1 ratio.

Field Study 3, Keesler AFB

Five different spray paint operations were evaluated:
Operations 1 and 4 involved spray-painting a tractor and the passenger-side door of a pickup truck respectively in a drive-in paint booth..
Operation 2 involved spray-panting a munitions handling cart and 2 small items in a walk-in paint booth.
Operations 3 and 5 involved spray-painting an aircraft engine and an aircraft stand respectively in a waterfall paint booth.

For operations 1, 2, 3 and 5, a Deft Catalyst (8010-01-023-4261) containing 30% biuret and 0.15% monomer was mixed with a Deft polyenamel in a 1:1 ratio. In operation 4, a Dupont 7575S activator/reducer containing aliphatic polyisocyanate was mixed with chroma clear base in a 1:4 ratio.

High volume low pressure sprayers to apply the paint were used during operations 1 and 4, while older-style Binks hand sprayers (35 psi) were used during operations 2 and 5. A "DevilBiss" TYPE-MBC sprayer (50 psi) was used for operation 3.

Area samples and personal samples were collected in the area of overspray and in the breathing zone respectively. Area samplers were 3-5 ft above the floor and about 4-5 ft downdraft from the equipment being painted.

Results and Discussion

Table I. (next page) shows the results of Field Study 1 conducted at Keesler AFB. Detectable HDI concentrations range from below the limit of detection to a high of 0.14 mg/m^3. For all spray paint operations, the HDI concentration obtained by using impinger collection (NIOSH Method 5521) is either the same (within experimental error) or higher than that obtained by collection on a filter (OSHA Method 42). The results indicate that 44% of the spray-painting operations exceeded the TLV of 0.034 mg/m^3 [1] so that personal protective equipment was needed.

The N-75 polyisocyanate concentration in air during spray-painting operations as determined by NIOSH Method 5521 ranged from 1.0 - 6.5 mg/m^3. At present there are no OSHA permissible exposure limits (PELs) or short-term exposure limits (STELs), no NIOSH recommended exposure limits (RELs), and no American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs) for polyisocyanates. The manufacturer (Miles) recommends a 1 mg/m^3 STEL and a 0.5 mg/m^3 8 hour TWA exposure limit, while the Swedish standard lists a 5-min STEL of 0.2 mg/m^3 and a TLV-TWA of 0.09 mg/m^3 [8]. The Oregon OSHA standard has a ceiling standard of 1 mg/m^3 and a 8-hr TWA of 0.5 mg/m^3 [9]. The spray-painting operations at Keesler AFB exceed the ceiling standard of 1 mg/m^3 for polyisocyanates in every case. These results underline the importance of analyzing for polyisocyanates especially since a definite link between occupational asthma and isocyanates has been established[4-7,19,20].

TABLE I. Field Study 1, Keesler AFB. Comparison of Diisocyanate Concentrations Obtained Using Impinger, Filter and Total Particulate Methods.

op	type	HDI (mg/m^3)		N-75 (mg/m^3)		T.P.
		NIOSH	OSHA	NIOSH	Ratio	(mg/m^3)
1	personal	0.01	-----	2.4		
	personal	0.003	-----	1.2		
	area	0.027	-----	6.5		
2	personal	0.017	<0.013	3.0		
	area	0.015	0.014	1.5		
	personal	0.022	<0.028	2.6		
	area	0.020	<0.059	3.0		
3	personal	<0.016	-----	1.0	0.8	4.0
	personal	0.007	-----			
	area	0.14	<0.026	1.6	2.9	15.2
	area	0.004	<0.016			
4	personal	0.11	-----	5.6		
	personal	0.12	-----	5.4		
	area	0.12	<0.012			
	area	0.023	<0.015	4.1	3.2	12.0
5	personal	0.14	-----	1.9	2.2	8.0
	area	0.059	0.025	2.8	4.3	15.8
6	personal	0.11	-----	2.3		
	area	0.043	<0.037	2.5	2.1	7.8
	blank	<0.0001	<0.001			

op = operation; ratio = concentration of N-75 polyisocyanate based on weight percent hardener and non-volatiles in paint

T.P. = total particulates

In an effort to find a simple method to analyze for polyisocyanate, total particulate concentrations were determined.These fell within a relatively small range, 4.0 - 15.8 mg/m^3. The ratio of polyisocyanate to total non-volatiles in the original paint formulation was 0.27 and 0.19. These ratios were used to calculate the mass ratio of polyisocyanate in the paint formulation.The values (se Table I, column 6) were within a factor of two of the NIOSH value.

If a linear regression analysis is attempted between the values of polyisocyanate obtained from NIOSH Method 5521 and the values from the ratio method, then a slope of 0.87 and a correlation coefficient, r, of 0.74 is obtained. This value exceeds the critical value of r = 0.46 for N = 14 samples and indicates a positive correlation[21].

In an effort to confirm the results obtained using OSHA Method 42, several of the samples were re analyzed using a novel capillary zone electrophoresis approach[22]. Table II shows the results obtained for six of the samples. The results from three samples were not used: the area sample from operation 1 exhibited poor precision for the HPLC analysis with up to 100% variability in the integrated area, while area samples from operations 5 and 6 had HDI concentrations which were below the limit of quantitation.

TABLE II. Keesler AFB, CZE and HPLC Results for HDI

Operation	Results (µg HDI)		Air Conc'n (mg/m^3)
	HPLC	CZE	
2	1.00	1.08	0.014
	0.67	0.64	0.059
3	0.57	0.57	0.026
4	0.39	0.47	0.012
	0.39	0.47	0.015
6	0.25	0.30	0.037

The pooled standard deviation for the HPLC data is 0.02 µg (N = 15), while for the CZE data it's 0.04 µg (N = 10). In all cases the results were comparable as measured by a plot of CZE response as a function of HPLC response. The r value was equal to 0.998 and the ratio of responses (slope) was 0.98.

In a comparison of CZE and HPLC, the limit of detection is the same, and the time reproducibility is comparable. Overall, the ability of CZE to analyze for diisocyanate in spray-paint operations is comparable to HPLC except that the CZE method offers 250,000 theoretical plates (calculated using the equation of Lukacs and Jorgenso[22]) as compared with the HPLC approach which provides 2500.

For all field samples, analyzed by CZE, the HDI peak was baseline-resolved from other polyurethane paint components, but for two samples, analyzed by HPLC, components in the paint formulation interfered in the analysis.

TABLE III . Tinker AFB, Comparison of Sorbent and Impinger Collection Methods.

sample	type	HDI		polyisocyanate	
		XAD-2	DMSO	XAD-2	DMSO
E1-1	painting	0.014	0.026	0.014	0.045
E2-1	operating manlift	0.005	0.083	0.074	0.160
A1-1	east side	0.021	0.017	0.070	0.085
A2-1	west side	0.014	0.014	0.094	0.164
E1-2	operating manlift	0.009	0.024	0.023	0.039
E2-2	painting	0.014	0.039	0.125	0.105
A1-2	east side	0.014	0.028	0.086	0.120
A2-2	west side	0.026	0.331	0.220	0.039

sample: E prefix denotes personal, A prefix denotes area sampling. The ventilation system was in the exhaust mode for the first four samples, while in the recirculation mode for the last four.

type denotes the type of labor being performed by the worker for personal and the location of the sampler for area sampling.

polyisocyanate concentrations are expressed in terms of mg of HDI/m^3 which would have the same number of isocyanate groups available for derivatization as the polyisocyanate.

XAD-2 and **DMSO** denote the sorbent and the solvent used to dissolve the tryptamine.

Table III.(previous page) shows the results of spray-painting operations conducted at Tinker AFB. For the analysis of the tryptamine derivative of HDI, desorbed from an XAD-2 resin, the HDI concentration ranges between 0.005 and 0.026 mg/m^3. For the analysis of HDI collected in the tryptamine DMSO solution, the concentration ranges between 0.014 and 0.083 mg/m^3 (excluding the results of sample A2-2 which seem too high). While the concentration of HDI in air as determined by collection on a solid sorbent, never exceeds the threshhold limit value (TLV) of 34 μg/m^3 [1], the results based on impinger collection show that two of seven samples exceed the TLV. 87% of the polyisocyanate concentrations exceed the TLV when measured in terms of HDI equivalents.

The relative collection efficiency of the tryptamine-coated XAD-2 sorbent(when compared to collection in a tryptamine DMSO solution) ranges from 6.3% to 126.6% with an average of 52.2%. For the polyisocyanate analysis, the average collection efficiency of XAD-2 is 66.6% when compared to that of the DMSO solution[15].In most cases, the results obtained with a sorbent tube are lower than those obtained by collection with an impinger. These results are in contrast to those obtained by Wu and Graind who found 90% recovery of phenylisocyanate when using tryptamine-coated XAD-2 as a sorbent[18]. The difference in the results can probably be ascribed to the reactivity of HDI which is higher than that of phenylisocyanate.

Table IV. (next page) shows the results for Field Study 2, conducted at Keesler AFB. The table compares the HDI polyisocyanate as determined using NIOSH Method 5521 (see MOPIP) and NIOSH Method:Isocyanates (see Tryp). The new NIOSH Method:Isocyanates gives higher results. The discrepancy may be due to one of two reasons:

1. Since HDI monomer was used to prepare the standards, the MOPIP results may be too low. In a previous report[12], the ec/uv ratio for polyisocyanate was found to be approximately 57% of that of the monomer. This lower response ratio would yield a calculated MOPIP value which would be 57 % of the "true" value. If the MOPIP results are recalculated taking this into account, the MOPIP and Tryp results are comparable.

2. The tryptamine results could be too high. All the peaks which gave a fluorescent response were summed in order to calculate the amount of polyisocyanate. Some of the peaks may be attributable to species other than isocyanate.

TABLE IV. Field Study 2, Keesler AFB. Comparison of Diisocyanate Amount Obtained Using NIOSH 5521 and NIOSH: Tryptamine Methods.

op	type	polyisocyanate (µg HDI/sample)		polyisocyanate (mg/m^3)	
		MOPIP	Tryp	MOPIP	Tryp
1	personal	72	-----	1.33	----
	area	118	-----	1.93	----
	personal	28	-----	0.53	----
	area	52	-----	0.69	----
2	personal	25	46	0.41	0.75
	area	45	70	0.64	1.00
3	area	9	20[1]	0.22	0.50
	personal	9	51[1,2]	0.33	1.89
4	personal	10	5[3]	1.11	0.56
	area	---	12[3]	----	0.80
5	personal	11	18	0.12	0.19
	area	15	31	0.16	0.33

op = operation; 1 Fluorescence detector response for polyisocyanate peaks not confirmed with electrochemical detector; 2 Sample frozen prior to analysis; 3 Sampling time was short (9-15 minutes).

The polyisocyanate in air during spray-painting operations as determined by NIOSH Method 5521 (see MOPIP) ranged from 0.12 - 1.93 mg/m^3, whereas, the polyisocyanate in air as determined by NIOSH Method:Isocyanates (see Tryp) ranged from 0.19 - 1.89 mg/m^3. The manufacturer (Miles) recommends a 1 mg/m^3 STEL and a 0.5 mg/m^3 8 hour TWA exposure limit, while the Swedish standard lists a 5-min STEL of 0.2 mg/m^3 and a TLV-TWA of 0.09 mg/m^3 (8). The Oregon OSHA standard has a ceiling standard of 1 mg/m^3 and a 8-hr TWA of 0.5 mg/m^3 (9).

The spray-painting operations at Keesler AFB in this study exceed the ceiling standard of 1 mg/m^3 for polyisocyanates about 25 % of the time.

Conclusions

1. NIOSH Method 5521 and NIOSH Method:Isocyanates which both use an impinger for sample collection give higher results for the analysis of HDI monomer than either a 1-(2-pyridyl)-piperazine-coated filter (OSHA Method 42) or a tryptamine-coated XAD-2 sorbent tube.

2. When evaluating field data, polyisocyanate concentrations need to be reported as well as monomer concentrations, even though there are no current, regulatory requirements for reporting polyisocyanate concentration. Field studies show that concentrations of polyisocyanate in excess of 1 mg/m^3 are common and therefore may pose a health hazard to spray paint workers.

3. Capillary zone electrophoresis may be used as an analytical tool for the separation of 1-(2-pyridyl)-piperazine-derivatized HDI. CZE offers better resolution of HDI than the validated HPLC approach especially when the HDI is in a complicated polyurethane paint formulation.

4. The concentration of polyisocyanate in air may be estimated (within a factor of two) from the concentration of particulates in air, and the percent hardener and non-volatiles in the paint formulation.

5. The results demonstrate that the new NIOSH method for Isocyanates, gives higher results than those obtained using the old NIOSH Method 5521.

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Development of the "Next Generation" of the Activities Interest Inventory for Selection of USAF Pilot Candidates

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Abstract

Several personality characteristics have been shown to be related to pilot performance. The purpose of this project was to develop an Activity Preference Inventory that was related to risk-taking attitudes. Based on the literature on risk-taking three factors were manipulated in the experimental inventory these being Presence of Others (Solitary, Social, or Competitive), Job Category (Work or Leisure), and Type of Risk (Physical Effort, Mental Effort, and Physical Risk). Results support the hypotheses that these three factors influenced activity preferences among participants. Scores derived from the experimental Activity Preference Inventory were found to be related to many of the personality characteristics that have been found to differentiate successful pilots. Specifically, there were significant relations between preferences and the Agreeableness, Extraversion, and Openness domains of personality and the Deliberation and Achievement Striving facets of Conscientiousness and the Angry Hostility and Impulsiveness facets of Neuroticism. In addition to being related to personality characteristics, preference scores were found to exhibit some differences based on age, gender, and race.

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Introduction

The selection of pilots who will be successful in training and subsequent performance as well as those who will remain with the service has been the focus of much research from the time of World War I (Siem, 1990). The high cost of training alone signifies the importance of further refining the selection system (Shull & Dolgin, 1989). Existing selection procedures have focused on cognitive abilities as measured by paper-and-pencil tests such as the Air Force Officer Qualifying Test (AFOQT) which measures pilot aptitude, verbal ability, and math knowledge (Skinner & Ree, 1987). More recently, there has been a growing body of research examining the relation of various personality characteristics with aviation performance, differentiating members of the aviation community and the general population, and pilot characteristics and safety (see Siem, 1990); however, the potential for socially desirable responding to many personality inventories raises concern as to the viability of the use of traditional paper-and-pencil personality inventories.

There also has been a renewed interest among industrial organizational psychologists in using personality characteristics to predict performance or success in training generally (Hough, 1992; Schmit, Weaver, Raymark, & Guion, 1992). The prevailing wisdom suggests that primary facets of personality (Costa & McCrae, 1992; Eysenck, 1992) may be more predictive of performance than the major dimensions of personality, especially if the primary facets are identified specifically for the position and the criterion of interest (Hough, 1992; Schmit, et al., 1992). For example, Hough in her meta-analysis of the relation between various personality characteristics reported differences in the strength of the relation depending on whether the criterion was training success, educational success, job proficiency, or commendable behavior. The personality characteristics that she included in her review were affiliation, potency, achievement, dependability, adjustment, agreeableness, intellectance, rugged individualism, and locus of control Therefore, it would appear that inclusion of specific personality characteristics in the selection procedure for Air Force pilot trainees would enhance the predictability of training success.

In addition to selecting the relevant personality characteristics, the method of assessing these personality characteristics is a major consideration. Carretta (1987) reports that the Air Force initiated a project for the development of the Basic Attributes Test (BAT) system in 1981. This system is now

nearing operational status and includes a number of tests designed to measure psychomotor aptitude, perceptual and cognitive processes, and personality and attitudinal characteristics. All tests are administered by computer which facilitates standardization and scoring. One of the tests included in the BAT is the Activities Interest Inventory which purports to measure survival attitudes and/or risk-taking attitudes (Carretta, 1987; Siem, Carretta, & Mercatante, 1987).

Discussion of the Problem

The Activities Interest Inventory requires individuals to indicate which activity from each of 81 pairs of activities that they would prefer. The activities differ with respect to the degree of threat to physical survival. However, examination of the items finds that they differ on a number of other dimensions as well. For example, some pairs differ based on whether one observes an activity or participates in the activities. Some of the choices are between individual activities versus group activities and some are between presumably well-learned activities versus practicing or learning an activity. Although subjects are told to assume that they have the necessary ability to perform each activity, there is no evidence that these instructions control for varying levels or experience or knowledge about the specific activities.

In examining the data from 509 candidates for the USAF Undergraduate Pilot Training program, it was found that subjects chose an average of 50.39 high-risk activities (sd=10.75) (Tetrick, 1992). A comparison of the response latencies for higher-risk choices versus lower-risk choices indicated that respondents took significantly longer to choose lower-risk activities than they did to select higher-risk activities ($M=4986.25$ and 4261.59, respectively; $F(1,503)=205.44$, $p<.01$). This is suggestive that response latencies may be related to social desirability given the situational demands. Unfortunately, there was not an independent measure of social desirability in the data set to examine the relation between response latencies and socially desirable responding.

Scores on the Activities Interest Inventory indicating risk preference were not related to scores on the psychoticism, inadequacy or cynicism scales contained in the Personality Profiler of the BAT. However, risk preference was significantly related to neuroticism ($r=-.19$) and extraversion ($r=.17$). Response latencies on higher-risk alternatives were significantly related to psychoticism scores ($r=-.13$), neuroticism scores ($r=-.14$), and cynicism ($r=.12$) while response latencies on lower-risk alternatives were significantly related to psychoticism scores ($r=-.15$), neuroticism ($r=-.17$), and cynicism ($r=-.16$). Response latencies on the risk preference measure were not significantly related to the other personality scales with the exception that latencies on the psychoticism items that were rejected were significantly related to response latencies for both higher-risk choices ($r=-.22$) and lower-risk choices ($r=-.20$). This pattern of relations suggests that risk-seeking as measured by the Activities Interest Inventory may not be subsumed under one of the five, global personality characteristics included in the Personality Profiler.

Neither the number of correct responses to an encoding task included in the BAT or the speed with which the decisions were made on the encoding task were significantly related to the scale scores on

psychoticism, neuroticism, extraversion, inadequacy, cynicism, or risk preference. However, the number of correct responses under the category identity condition of the encoding task was positively related to the response latencies in selecting higher-risk alternatives (r=.13) as well as in selecting lower-risk alternatives (r=.13) while the decision time in making the correct choice under both the name identity and category identity conditions was related to the response time in selecting higher-risk alternatives (r=.15 and .13, respectively). Verbal and quantitative ability as measured on the AFOQT were not related to scores on psychoticism, neuroticism, extraversion, inadequacy, or cynicism; however, verbal ability was significantly to risk preference (r=.12) and quantitative ability was significantly related to response latencies for higher-risk choices (r=.24) and lower-risk choices (r=-.14) as well as encoding speed under the physical identity rule of the encoding task (r=-.21), name identity rule (r=-.20), and the category identity rule (r=-.19). Thus while there were some significant relations among response latencies on some of the tests and verbal ability, the strength of these relations does not support the interpretation of response latencies as indicative of intelligence or speed of information processing, at least not exclusively (Vernon, 1987).

The zero-order correlations of the personality and ability measures with training success were found to be roughly comparable in magnitude to those reported by Hough (1992). Three of the five personality measures, psychoticism, inadequacy, and cynicism, were the only variables that had a significant zero-order correlation with training outcome (r=-.11, r=-.13, and r=-.13, respectively. Scores on the Activities Interest Inventory were not significantly related to training outcomes although the response latencies for lower-risk choices approached significance (r=.10, p<.10). AFOQT scores also were not significantly related to training outcome. However, the participants in this study had undergone considerable selection prior to reaching this point in their career with the USAF, and therefore, the lack of relations for the ability measures of the AFOQT may be a function of restriction of range. It also may be the case that there was restriction of range on the Activities Interest Inventory as well as the other personality measures for similar reasons. There were several items (20 of the 81 pairs of activities) where the majority, in fact over 80% of the respondents, selected the same response.

Two primary concerns prompt the proposed research. First, there is little evidence for the construct validity of the Activities Interest Inventory as a measure of survival attitudes or risk-taking. Factor analyses of subsets of the items indicated that there were multiple factors present and the first factor did not account for more than 15% in any of the analyses. This multidimensionality is consistent with the various factors that represent differences in the choices described above. Second, several items on the inventory are either outdated (e.g., references to the Congo) or do not differentiate well across individuals (e.g., 97% of 509 participants indicated that they would rather fly an airplane than drive a truck). This latter finding may be indicative of socially desirable responding or demand characteristics. If such is the case in an experimental, research setting, one can only expect it to become more salient in an operational, selection setting. Focusing on these concerns, an experimental version of an Activity

Preference Inventory was developed as the next generation of the Activities Interest Inventory and the psychometric properties examined. Further, the relations of scores on the experimental inventory with three personality inventories were assessed.

Study 1 - Item Development

The first phase of this project involved the generation of potential activities to be included in the new version of the Activities Interest Inventory. A review of the literature on perceived risk suggested five dimensions that were hypothesized to influence individuals' perceived risk (Arabie & Maschmeyer, 1988; Cheron & Ritchie, 1982; Dahlback, 1990; Levenson, 1990; Sitkin & Pablo, 1992; Wyatt, 1990). These dimensions were (1) presence of others, (2) physical risk, (3) psychological risk, (4) physical effort, and (5) mental effort. In addition to the 81 activities included in the original Activities Interest Inventory, omitting or modifying those items which were obsolete, an additional 402 activities were generated from the literature covering the domains of leisure activities, work-related activities, financial/consumer activities, and self-care and health maintenance activities. Where appropriate, versions of the activities that implied that the activity was done by oneself, as a member of a team, in a competitive situation, and in a social situation (e.g., with other people but not as a competitive activity) were created.

Method

Participants were solicited from psychology classes at Wayne State University to rate the activities on the amount of physical risk, psychological risk, mental effort, and physical effort involved in each activity. In addition, each participant indicated how familiar they were with the activity and whether they had any actual experience with the activity. Also, all respondents responded to an abbreviated form of Zuckerman's (1983) sensation seeking scales of thrill and adventure seeking, experience seeking, disinhibition, and boredom avoidance and various demographic questions.

Results

Of the 387 participants in this phase of the project, 33.5% were men, 27.9% were working full-time and 51.7% were working part-time. The average age of the respondents was 23.65 with 52.2% of the respondents being between the ages of 17 and 21. Fifty-two percent were white and 38% were African-American with 51% of the respondents describing themselves as coming from middle class families, 21% describing themselves as coming from lower middle class families, and 28% describing themselves as coming from upper middle class families. Mean ratings across activities are shown below and indicate that there was sufficient variability among the activities on the four dimensions of physical risk, psychological risk, physical effort, and mental effort. Familiarity and experience with the activities were correlated .97 and, as expected, significantly related to the other ratings. Familiarity was correlated with ratings of physical risk ($r=-.56$), with psychological risk ($r=-.44$), with physical effort ($r=-.59$), and with mental effort ($r=-.59$).

Mean Ratings Across Activities				
Rating	Mean	SD	Minimum	Maximum
Physical Risk	3.19	1.54	1.00	6.52
Psychological Risk	2.72	0.78	1.18	5.43
Physical Effort	3.97	1.40	1.22	6.42
Mental Effort	3.96	1.08	1.70	6.63
Familiarity	3.23	1.24	1.32	6.47
Experience	1.49	0.51	1.00	2.92

The ratings of physical risk, psychological risk, physical effort, and mental effort of the activities were significantly related. Most of the correlations were moderate with the exception of a strong relation between ratings of physical risk and physical effort (r=.77) which suggested that these may represent redundant dimensions of risk.

Correlations among ratings for activities

Physical Risk	1.00			
Psychological Risk	0.43	1.00		
Physical Effort	0.77	0.35	1.00	
Mental Effort	0.42	0.39	0.43	1.00

A multivariate analysis of variance with familiarity treated as a covariate resulted in significant differences among the four categories of presence of others for psychological risk, physical effort, and mental effort. There was no significant difference after partialling the effect of familiarity for physical risk ratings. The observed and adjusted means by category across activities are shown below. The same general pattern of ratings were evident for physical risk, psychological risk, physical effort, and mental effort with solitary activities being rated lower than team and competitive activities. Social activities were typically rated more closely to solitary activities than team or competitive activities. Therefore, the results support the notion that presence of others affects individual's perception of risk. Further, while the ratings of physical risk and physical effort were quite strongly related, the results of the MANOVA suggest that it may be meaningful to maintain both of these dimensions.

Summary of Ratings Across Activities

Rating	Mean	Adj. Mean
Physical Risk		
Solitary	2.99	3.13
Team	3.60	3.30
Competitive	3.35	3.21
Social	3.05	3.35
Psychological Risk		
Solitary	2.47	2.53
Team	2.80	2.68
Competitive	3.14	3.08
Social	2.75	2.87
Physical Effort		
Solitary	3.46	3.55
Team	4.50	4.31
Competitive	4.68	4.59
Social	3.80	3.99
Mental Effort		
Solitary	3.70	3.80
Team	4.45	4.45
Competitive	4.51	4.42
Social	3.58	3.78

Lastly, the relations between risk ratings and sensation-seeking were examined. Whether an individual had actually performed the activity was positively related with all four dimensions of sensation-seeking (Thrill and Adventure Seeking, r=.52; Experience Seeking, r=.31; Disinhibition, r=.25; and Boredom Avoidance, r=.21) although familiarity with the activity was only significantly related to Thrill and Adventure Seeking (r=.21). Mental effort was negatively related to Disinhibition (r=-.19) and Boredom Avoidance (r=-.24) and physical risk was only significantly related to Thrill and Adventure Seeking (r=-.30). Psychological risk and physical effort were not significantly related to any of the dimensions of sensation-seeking. There were significant differences on all four dimensions of the sensation-seeking scale by race (Thrill and Adventure Seeking, r=.44; Experience Seeking, r=.15; Disinhibition, r=.14; and Boredom Avoidance, r=.14) and there were significant gender differences on three of the four dimensions (Thrill and Adventure Seeking, r=-.27; Experience Seeking, r=-.12; and Disinhibition, r=-.31). Therefore, separate ANOVAs were run for each activity to examine gender and race differences. Of the 483 activities, 342 activities exhibited significant gender or race differences and were excluded from further consideration in the development of the experimental Activity Preference Inventory leaving a pool of 141 activities.

Study 2 - Effect of Instructions

A question of interest in the creation of the final form of the Activity Preference Inventory was whether instructions to subjects to assume that they had the ability to perform the activities was sufficient to control for varying levels of experience with the activities, especially given the relation between familiarity and experience on ratings of risk. The literature suggested that subjects may prefer activities that they currently have the ability to do and not attend to the instructions. To examine this question, a second study was conducted to evaluate the effects of the instructions on the original Activities Interest Inventory. One form of the instrument contained explicit instructions to respondents to assume that they had the ability to perform the activities while a second form's instructions remained silent as to whether the respondents were to assume that they had the ability to perform the activities.

Method and Results

Two inventories were constructed and administered to 67 college students (67.2% female) from Wayne State University. Each inventory used 80 of the 81 activity pairs from the original Activity Interest Inventory; the pair with the item referring to being a missionary in the Belgian Congo was dropped). The forms differed only in the written instructions given to the subjects and were randomly assigned to the participants. For one set of subjects (n=34), the sentence "Assume you have the necessary ability to engage in all of these activities." was included in the instructions. The other group of subjects (n=33) did not receive this instruction. The two groups also indicated their familiarity with each of the 160 activities included in the inventory. Analysis of variance tests indicated that there were group differences on only 14 of the 160 activities. However, when a Bonferroni adjustment to the alpha level to reflect the number of tests that were conducted was made, the two groups did not differ on any of the items. This suggests that the subjects in the two groups had similar levels of experience with the activities. Further, subjects' scores on the instrument were not related to age, socio-economics status, work status or gender. However, there were significant race differences with whites scoring higher than non-whites (means=34.95 and 26.36, respectively, $p<.05$).

To evaluate the influence of the instructions, test scores were computed for each subject using the original Air Force scoring key. Mean differences between the two groups of subjects based on instructions were then evaluated using analysis of variance. The results indicated that there were no significant differences between the two groups of subjects. Instructing subjects to assume they had the ability to do each activity did not influence their choices. Therefore, it was decided that the instructions should remain unchanged in developing the final form of the experimental Activity Preference Inventory.

Study 3 Examination of the Experimental Activity Preference Inventory

The final study in this project was to generate an experimental Activity Preference Inventory and examine its relation to various personality measures. The original Activity Interest Inventory used a forced choice format which has been considered by some to provide better psychometric properties

guarding against socially desirable responding (Jackson, Neill, & Bevan, 1973; Nederof, 1985; Tripathi & Sengupta, 1986) although the data are not conclusively in support of this approach (Deaton, Glasnapp, & Poggio, 1980; Juni & Koenig, 1982; Nederof, 1985; Ray, 1990; Tenopyr, 1988; Zavala, 1965). Based on our review of the literature, it was decided to retain a forced-choice format systematically varying presence of others, physical risk, physical effort, and mental effort.

Method

Subjects were recruited from psychology classes at Wayne State University; 254 volunteers participated in the study for extra-credit in their respective courses. Twenty-four percent of the participants were male, 48% were working part-time and 26% were working full-time, and 35% were African-American. The average age of the respondents was 26 years old with 71% being between the ages of 17 and 26. All subjects completed one of the two versions of the experimental Activity Preference Inventory that was randomly assigned to them as well as three personality inventories and a demographic questionnaire.

The Activity Preference Inventory

The Activity Preference Inventory was constructed based on the results of the first study described above. Of the 141 activities which did not have significantly different ratings across men and women or racial groups, 27 activities which had versions that represented three levels of presence of others (solitary, team, social) were selected to represent high or medium levels of physical risk, physical effort, and mental effort based on the mean ratings from study 1. Using the four factors of presence of others with 3 levels, physical risk with 2 levels, physical effort with 2 levels, and mental effort with 2 levels, activities were grouped in triplets to represent a 3X2X2X2 factorial design resulting in 136 stimuli triplets. Order within each triplet was randomly assigned so that the target activity (high on at least one factor) was not consistently the first, second, or third activity within the triplet. Stimuli triplets were then randomly ordered on the experimental instrument. Two versions of the experimental Activity Preference Inventory were generated which differed in their instructions to the respondents. One form required respondents to simply check the one activity among the three activities within the triplet that they would most prefer to do. The other form requested that subjects rank order the three activities in terms of their preference to engage in each activity.

Other Instruments

In addition to one of two experimental versions of the Activity Preference Inventory, participants completed Bartone, Ursano, Wright, and Ingraham's (1989) Hardiness Scale, Christie's Adjective Checklist that measures the "big five" dimensions of personality, and the NEO PI-R (Costa & McCrae, 1992). The Hardiness Scale includes 45 statements to which the subject indicates the degree of veracity for each statement (e.g., "Politicians run our lives") on a four point Likert-type scale (0=Not at all to 3=Completely true). The 45 statements comprise three dimensions each measured with 15 items: challenge (a zest for living that leads one to perceive changes as exciting and as opportunities for growth

rather than threats to security or survival), control (a sense of autonomy and ability to influence one's own destiny), and commitment (a sense of meaning and purpose to one's existence encompassing self, others, and work). The Adjective Checklist is a 30 item inventory on which subjects indicate the degree to which each adjective describes themselves based on a 6-point Likert-type scale ranging from 1=extremely uncharacteristic of you to 6=extremely characteristic of you. The 30 items represent Agreeableness, Openness, Neuroticism, Conscientiousness, and Extraversion. The NEO PI-R includes 240 statements to which respondents indicate on a 5-point scale their degree of agreement with each statement ranging from 0=strongly disagree to 4=strongly agree. The inventory provides measures of the "big five" dimensions of personality and associated facets: Neuroticism (anxiety, angry hostility, depression, self-consciousness, impulsiveness, and vulnerability); Extraversion (warmth, gregariousness, assertiveness, activity, excitement-seeking, positive emotions); Openness (fantasy, aesthetics, feelings, actions, ideas, values); Agreeableness (trust, straightforwardness, altruism, compliance, modesty, tender-mindedness); and Conscientiousness (competence, order, dutifulness, achievement-seeking, self-discipline, deliberation).

Results

Effects of Instruction Set

The first analyses addressed differences between the two experimental versions of the Activity Preference Inventory which differed in the response required of the subjects. One version asked subjects to rank their activity preferences within each triplet of activities while the other asked subjects to choose the single activity which they would most prefer to do. It was reasoned that by having subjects rank order the activities greater precision might be gained over the simple "first choice" procedure. Each form was administered to 127 subjects. To evaluate whether there were differences in first choice preference scores from the subjects who completed the rank order task, the activity which the subjects ranked as most preferred was scored a "1" and the other two choices were scored a "0". The frequency with which an activity was chosen across the two groups was then compared. Results of the analyses indicated that there were no significant differences suggesting that the two instructions did not influence the subjects' responses. Therefore, the decision was made to use only the "most preferred" score for all individuals in subsequent analyses.

Experimental Inventory Characteristics

The first question to be addressed was whether the activities included had sufficient variability, that is were there activities that were selected consistently by almost all of the respondents or almost none of the respondents. The proportion of times respondents selected each activity are shown below with the average proportion of times a given activity was selected ranging from 11.7% to 70.3%. Therefore, it was concluded that the activities included in the experimental version of the Activity Preference Inventory represented sufficient variability to differentiate individuals.

	Proportion Of Times Respondents Selected Each Activity			
Activity	Mean	StdDev	Minimum	Maximum
Target Activities				
2.7.3	55.3	37.8	.0	100.0
6.6.2	49.7	35.6	.0	100.0
8.2.2	68.0	38.1	.0	100.0
8.2.3	60.6	41.2	.0	100.0
8.4.1	28.7	31.0	.0	100.0
8.4.2	36.4	32.1	.0	100.0
8.7.3	30.4	32.8	.0	100.0
9.5.1	12.4	24.8	.0	100.0
10.7.2	16.1	29.0	.0	100.0
11.1.3	47.1	40.0	.0	100.0
14.6.1	27.7	33.5	.0	100.0
16.2.1	38.7	42.4	.0	100.0
18.3.1	40.9	30.5	.0	100.0
29.4.1	11.7	23.5	.0	100.0
30.1.2	31.4	39.0	.0	100.0
30.5.3	42.4	42.8	.0	100.0
37.3.2	39.8	41.2	.0	100.0
38.7.3	49.9	27.5	.0	100.0
41.7.1	70.3	34.6	.0	100.0
42.5.3	63.5	39.8	.0	100.0
44.4.1	59.3	38.9	.0	100.0
44.4.3	53.9	39.0	.0	100.0
45.2.1	42.6	40.4	.0	100.0
45.4.2	59.3	37.4	.0	100.0
Non-target Items				
5.6.2	15.1	19.7	.0	97.7
24.1.3	33.9	23.5	.0	93.2
25.5.2	47.6	29.0	.0	97.7
29.3.1	23.1	21.5	.0	95.5
31.4.3	27.0	21.8	.0	95.5
32.6.1	21.4	31.2	.0	100.0

Since the experimental inventory was developed by manipulating three factors (e.g., Presence of Others, Job Category, and Type of Risk), a repeated measures analysis of variance was conducted to examine the effects of these factors. The results of that analysis are shown below and show that all main effects and two-way interactions were significant. This supports the earlier contention that contextual effects of activities can affect individuals' preferences.

Results of Repeated Measures Analysis of Variance

	Avg. F	Eta Sqd.	Partial Eta Sqd.
Presence of Others (P)	79.62*	.404	.241
Job Category (J)	34.64*	.122	.122
Risk (PR, PE, ME)	40.28*	.258	.138
P by J	52.79*	.292	.174
P by Risk	28.97*	.299	.103
J by Risk	29.37*	.195	.105

Note. *=p<.01

Given these results, a total of 29 scores were generated for each individual representing the proportion of times a target item was selected based on the factors represented by each activity. The resulting scores representing the main effects were Solitary, Social, Competitive, Work, Leisure, Physical Effort, Mental Effort, and Physical Risk, and for each of the two-way interactions the scores were Solitary-Work (WORKALON), Solitary-Leisure (LEISALON), Social-Work (WORKSOCL), Social-Leisure (LEISSOCL), Competitive-Work (WORKCOMP), Competitive-Leisure (LEISCOMP), Solitary-High Physical Effort (PHYEALON), Solitary-High Mental Effort (MENEALON), Solitary-High Physical Risk (PHYRALON), Social-High Physical Effort (PHYESOCL), Social-High Mental Effort (MENESOCL), Social-High Physical Risk (PHYRSOCL), Competitive-High Physical Effort (PHYECOMP), Competitive-High Mental Effort (MENECOMP), Competitive-High Physical Risk (PHYRCOMP), Work-High Physical Effort (PHYEWORK), Work-High Mental Effort (MENEWORK), Work-High Physical Risk (PHYRWORK), Leisure-High Physical Effort (PHYELEIS), Leisure-High Mental Effort (MENELEIS), and Leisure-High Physical Risk (PHRYLEIS).

The means and standard deviations of these scores are shown below as well as the correlations among the scores. The means and standard deviations indicate that there was considerable variability across individuals; however, as evidenced by the correlations, the scores were significantly correlated with each other. Results of a principle components analysis with varimax rotation of the two-way interaction scores suggested four dimensions: Competitive Activity Preference, Solitary Activity Preference, Social Leisure Activity Preference, and Social Work Activity Preference. However, rather than to collapse scores at this phase in the development of the experimental Activity Preference Inventory, it was decided to retain all scores in examining the relations with the personality characteristics and demographics.

Means and Standard Deviations	Mean	s.d.
Main Effects		
Presence of Others		
Solitary	27.85	10.33
Social	35.59	13.03
Competitive	37.01	12.52
Job Category		
Work	36.23	16.07
Leisure	42.58	19.13
Risk		
Physical Effort	40.64	15.05
Mental Effort	40.40	16.64
Physical Risk	36.16	15.68
Two-way Interactions		
Presence of Others by Job Category		
Solitary		
Work	33.05	18.21
Leisure	27.42	18.92
Social		
Work	35.28	29.51
Leisure	44.26	26.14
Competitive		
Work	40.57	21.80
Leisure	56.07	27.43
Presence of Others by Risk		
Solitary		
Physical Effort	31.70	14.53
Mental Effort	31.42	17.81
Physical Risk	27.67	16.86
Social		
Physical Effort	39.81	24.47
Mental Effort	43.20	25.22
Physical Risk	36.16	23.16
Competitive		
Physical Effort	50.35	20.87
Mental Effort	47.58	21.08
Physical Risk	47.80	22.78
Job Category by Risk		
Work		
Physical Effort	36.36	15.88
Mental Effort	38.93	18.34
Physical Risk	33.53	16.00
Leisure		
Physical Effort	45.01	19.66
Mental Effort	41.93	19.78
Physical Risk	40.80	20.46

Correlation Coefficients among Main Effect Variables

	1	2	3	4	5	6	7	8
1. Solitary	1.00							
2. Social	-.43**	1.00						
3. Competitive	-.44**	-.60**	1.00					
4. Work	-.05	.02	.02	1.00				
5. Leisure	-.01	-.07	.09	.50**	1.00			
6. Physical Effort	-.06	-.00	.07	.81**	.85**	1.00		
7. Mental Effort	-.04	-.05	.09	.84**	.84**	.90**	1.00	
8. Physical Effort	.01	-.06	.05	.77**	.89**	.90**	.91**	1.00

Note. * - Signif. LE .05; ** - Signif. LE .01 (2-tailed)

Correlation Coefficients among Presence of Others by Job Category Variables

	1	2	3	4	5	6
1. WORKALON	1.00					
2. LEISALON	.40**	1.00				
3. WORKSOCL	.63**	.17**	1.00			
4. LEISSOCL	.45**	.26**	.43**	1.00		
5. WORKCOMP	-.11	-.11	.05	-.06	1.00	
6. LEISCOMP	.38**	.34**	.33**	.61**	.36**	1.00

Note. * - Signif. LE .05; ** - Signif. LE .01 (2-tailed); WORK=Work Activities, LEIS=Leisure Activities, ALON=Solitary Activities, SOCL=Social Activities, COMP=Competitive Activities

Correlation Coefficients among Presence of Others by Risk Variables

	1	2	3	4	5	6	7	8	9
1 PHYEALON	1.00								
2 MENEALON	.84**	1.00							
3 PHYRALON	.82**	.86**	1.00						
4 PHYESOCL	.46**	.44**	.44**	1.00					
5 MENESOCL	.50**	.53**	.49**	.90**	1.00				
6 PHYRSOCL	.48**	.51**	.50**	.89**	.94**	1.00			
7 PHYECOMP	.17**	.22**	.18**	.35**	.47**	.35**	1.00		
8 MENECOMP	.13*	.24**	.20**	.27**	.40**	.28**	.85**	1.00	
9 PHYRCOMP	.16**	.21**	.19**	.26**	.37**	.29**	.88**	.83**	1.00

Note. * - Signif. LE .05; ** - Signif. LE .01 (2-tailed); PHYE=Physical Effort, MENE=Mental Effort, PHYR=Physical Risk, ALON=Solitary, SOCL=Social, COMP=Competitive

Correlation Coefficients among Job Category by Risk Variables

	1	2	3	4	5	6
1. PHYEWORK	1.00					
2. MENEWORK	.86**	1.00				
3. PHYRWORK	.83**	.94**	1.00			
4. PHYELEIS	.41**	.47**	.51**	1.00		
5. MENELEIS	.41**	.51**	.54**	.89**	1.00	
6. PHYRLEIS	.34**	.43**	.47**	.88**	.84**	1.00

Note. * - Signif. LE .05; ** - Signif. LE .01 (2-tailed); PHYE=Physical Effort, MENE=Mental Effort, PHYR=Physical Risk, WORK=Work Activities, LEIS=Leisure Activities

Correlation Coefficients between Presence of Others by Job Category Variables with Job Category by Risk Variables

	WORK			LEISURE		
	PHYE	MENE	PHYR	PHYE	MENE	PHYR
WORKALON	.66**	.68**	.69**	.50**	.55**	.44**
LEISALON	.09	.21**	.30**	.57**	.60**	.58**
WORKSOCL	.85**	.82**	.85**	.41**	.43**	.34**
LEISSOCL	.38**	.38**	.41**	.83**	.77**	.79**
WORKCOMP	.36**	.48**	.41**	.10	.08	.12*
LEISCOMP	.42**	.53**	.51**	.83**	.83**	.83**

Note. * - Signif. LE .05; ** - Signif. LE .01 (2-tailed); PHYE=Physical Effort, MENE=Mental Effort, PHYR=Physical Risk, WORK=Work Activities, LEIS=Leisure Activities, ALON=Solitary, SOCL=Social, COMP=Competitive

Correlation Coefficients between Presence of Others by Risk Variables and Presence of Others by Job Category Variables

	ALON		SOCL		COMP	
	WORK	LEIS	WORK	LEIS	WORK	LEIS
PHYEALON	.79**	.76**	.45**	.38**	-.15*	.36**
MENEALON	.81**	.78**	.48**	.37**	-.07	.41**
PHYRALON	.75**	.84**	.41**	.42**	-.17**	.43**
PHYESOCL	.61**	.19**	.83**	.78**	-.04	.48**
MENESOCL	.64**	.27**	.86**	.79**	.06	.59**
PHYRSOCL	.61**	.27**	.82**	.82**	-.02	.50**
PHYECOMP	.18**	.16**	.26**	.43**	.72**	.85**
MENECOMP	.21**	.15*	.24**	.32**	.74**	.81**
PHYRCOMP	.15*	.1956**	.21**	.33**	.76**	.81**

Note. * - Signif. LE .05; ** - Signif. LE .01 (2-tailed); PHYE=Physical Effort, MENE=Mental Effort, PHYR=Physical Risk, WORK=Work Activities, LEIS=Leisure Activities, ALON=Solitary, SOCL=Social, COMP=Competitive

Correlation Coefficients between Presence of Others by Risk Variables with Job Category by Risk Variables

	WORK PHYE	WORK MENE	WORK PHYR	LEIS PHYE	LEIS MENE	LEIS PHYR
PHYEALON	.48**	.46**	.51**	.60**	.60**	.53**
MENEALON	.45**	.60**	.58**	.59**	.66**	.56**
PHYRALON	.33**	.42**	.56**	.62**	.68**	.64**
PHYESOCL	.77**	.64**	.67**	.67**	.62**	.59**
MENESOCL	.72**	.76**	.79**	.72**	.74**	.64**
PHYRSOCL	.65**	.69**	.73**	.70**	.67**	.68**
PHYECOMP	.46**	.57**	.54**	.69**	.59**	.60**
MENECOMP	.44**	.59**	.55**	.52**	.64**	.52**
PHYRCOMP	.43**	.56**	.52**	.56**	.51**	.67**

Note. * - Signif. LE .05; ** - Signif. LE .01 (2-tailed); PHYE=Physical Effort, MENE=Mental Effort, PHYR=Physical Risk, WORK=Work Activities, LEIS=Leisure Activities, ALON=Solitary, SOCL=Social, COMP=Competitive

Relations between Experimental Inventory Scores and Personality and Demographics

Prior to examining the relations between the scores derived from the experimental version of the Activity Preference Inventory, additional scores were derived representing the proportion of preferred activities based on Presence of Others and Job Category across both target and non-target activities. These correlations are shown below. There were no race differences on the proportion of Solitary, Social, and Competitive activities chosen nor were there any differences on the proportion of Work and Leisure activities chosen by race. Younger respondents chose a higher proportion of Competitive activities than did older respondents but there were no significant differences in the number of Solitary, Social, Work, and Leisure activities based on age. Comparisons based on gender revealed more significant differences. Women tended to select a higher proportion of Social activities and men tended to select a higher proportion of Competitive activities. In addition, women tended to select a higher proportion of Work activities while men tended to select a higher proportion of Leisure activities across both target and non-target items.

The proportion of Solitary activities preferred was negatively related to two of the dimensions of the Hardiness Scale (e.g., Control and Commitment) indicating that the more individuals preferred solitary activities tended to have a lower sense of autonomy as well as a lower sense of meaning and purpose in their lives. The proportion of Competitive activities were not related to any of the dimensions of Hardiness, but the proportion of Social activities chosen was positively related to Commitment. The proportion of Work and Leisure activities were related to the Commitment dimensions of Hardiness only, but as would be expected in the opposite direction. Individuals selecting a higher proportion of Work activities tended to have higher Commitment scores and individuals selecting a higher proportion of Leisure activities tended to have lower levels of Commitment.

Similarly there were significant relations with measure of the five domains of personality as measured by the NEO-PI. Individuals who selected more Solitary activities tended to score lower on Agreeableness and Extraversion while individuals who selected more Social activities tended to score higher on Agreeableness although there was no relation to Extraversion. Individuals who selected more Competitive activities tended to score lower on Agreeableness with the same magnitude of relation as was found between the proportion of Solitary activities. However, individuals who chose more Competitive activities tended to also have higher scores on Extraversion. Thus, there was a differential pattern of relations based on the proportion of activities preferred across the Presence of Others factor and personality. With respect to the proportion of Work and Leisure activities preferred, there was only one significant relation that being with Agreeableness. Higher proportions of work activities selected tended to be associated with higher scores on Agreeableness while higher proportions of leisure activities selected tended to be associated with lower scores on Agreeableness. These differences appear to be a result of differences on the facets of altruism and compliance.

Correlations among Presence of Others and Job Category Preferences
across Target and Non-Target Activities with Personality Characteristics and Demographics

	Solitary	Social	Competitive	Work	Leisure
Demographics					
Age	.08	.11	-.18**	.12	-.11
Gender	.02	.19**	-.21**	.24**	-.24**
Race	-.00	.04	-.02	-.11	.11
Hardiness Scales					
Control	-.15*	.10	.03	.11	-.11
Commitment	-.20**	.16*	.01	.13*	-.14*
Challenge	.00	.06	-.07	-.00	.00
NEO-PI					
Agreeableness	-.12*	.24**	-.12*	.18**	-.18**
Conscientiousness	-.05	.05	-.00	.10	-.09
Extraversion	-.30**	.09	.17**	.05	-.04
Neuroticism	.02	.02	-.04	.04	-.04
Openness	-.06	.13*	-.07	.06	-.05
Adjective Checklist					
Agreeableness	-.09	.08	-.00	.08	-.09
Conscientiousness	-.04	-.02	.05	.05	-.06
Extraversion	.22**	-.06	-.15*	.00	-.02
Neuroticism	.03	-.09	.06	-.10	.09
Openness	.06	-.00	-.04	-.00	.01

Correlations among Presence of Others and Job Category Preferences
across Target and Non-Target Activities with Personality Characteristics and Demographics

	Solitary	Social	Competitive	Work	Leisure
NEO-PI Facets					
Agreeableness Facets					
A1: Trust	-.21**	.22**	-.02	.11	-.11
A2: Straightforwardness	-.00	.19**	-.19**	.13*	-.13
A3: Altruism	-.11	.15*	-.03	.13*	-.12
A4: Compliance	.06	.03	-.09	.00	-.00
A5: Modesty	.04	.11	-.15*	.11	-.10
A6: Tender-Mindedness	-.07	.18**	-.11	.17**	-.16**
Conscientiousness Facets					
C1: Competence	-.05	.07	-.02	.08	-.07
C2: Order	.05	-.08	.02	-.00	.00
C3: Dutifulness	-.10	.13*	-.04	.09	-.09
C4: Achievement Striving	-.07	.05	.01	.05	-.05
C5: Self-Discipline	-.05	.05	-.00	.05	-.05
C6: Deliberation	.00	.00	-.00	.04	-.04
Extraversion Facets					
E1: Warmth	-.20**	.13*	.04	.08	-.08
E2: Gregariousness	-.38**	.13*	.20**	.09	-.09
E3: Assertiveness	-.20**	-.00	.19**	-.02	.03
E4: Activity	-.06	-.03	.09	-.06	.06
E5: Excitement Seeking	-.20**	-.06	.24**	-.06	.07
E6: Positive Emotions	-.13*	.06	.06	.04	-.03
Neuroticism Facets					
N1: Anxiety	-.01	.14*	-.13*	.11	-.11
N2: Angry Hostility	-.00	-.07	.07	-.02	.02
N3: Depression	.07	-.03	-.03	-.03	.02
N4: Self-Consciousness	.11	-.11	.00	-.03	.03
N5: Impulsiveness	-.01	-.09	.10	-.11	.11
N6: Vulnerability	.08	.07	-.14*	.06	-.06
Openness Facets					
O1: Fantasy	.03	-.01	-.01	-.07	.08
O2: Aesthetics	.04	.10	-.14*	.04	-.04
O3: Feelings	-.06	.02	.04	-.02	.03
O4: Actions	-.07	.16*	-.08	.09	-.08
O5: Ideas	-.05	.03	.01	-.02	.02
O6: Values	-.03	.10	-.07	.03	-.02

Note. *- Signif. LE .05, **- Signif. LE .01, (2-tailed); Sex: 1=men, 2=women; Race: 1=African-American, 2=Other

The correlations among the scores on the experimental Activity Preference Inventory with the three dimensions of hardiness, the five domain scores of the NEO-PI, the Adjective Checklist, and the facet scores on the NEO-PI are shown below. When considering target activities only, which have at least one component of risk that was higher than the non-target items (e.g., physical effort, mental effort, and

physical risk), revealed a somewhat different pattern of relations with the personality characteristics for the Presence of Others and Job Category factors than presented above.

Scores representing the main effects of Presence of Others, Job Category, and Type of Risk were all significantly related to at least some of the personality dimensions. Work, High Mental Effort, and High Physical Risk scores were related to the Control dimension of Hardiness, where Leisure, High Physical Effort, High Mental Effort, and High Physical Risk scores were related to the Challenge dimension of Hardiness. Only Competitive Activities Preferences was significantly related to the Commitment dimension of Hardiness. The other scores based on the Presence of Others for the target items were not related to any of the dimensions of Hardiness. With respect to the five domains of personality as measured by the NEO-PI, Extraversion was significantly related to all main effect scores with the exception of Social Activities Preferences. The relations were all positive with the exception of Solitary Activities Preferences which were negatively related with Extraversion. All three dimensions of Presence of Others were significantly related to Agreeableness although Solitary Activities and Competitive Activities Preferences were negatively related to Agreeableness while Social Activities Preferences were positively related to Agreeableness.. There were significant relations between the main effect scores of Social Activities, Leisure Activities, High Physical Effort Activities, High Mental Effort Activities, and High Physical Risk Activities with Openness. Conscientiouness and Neuroticism were not related with any of the scores representing main effects. The results were somewhat different for the Adjective Checklist measures of the five domains of personality. Extraversion was significantly related with Social Activities, Competitive Activities, Leisure Activities, and High Physical Risk Activities Preferences scores. (It should be noted that the extraversion scale was scored such that high scores on this factor actually represent less extraversion so that the direction of the relation appears to be the opposite of the NEO-PI extraversion measure in the tables.) Solitary Activities and Work Activities Preferences were not related to this measure of extraversion. Also, there were no significant relations with Agreeableness while there were with the NEO-PI and only Leisure Activities and High Mental Effort Activities Preferences scores were related to Openness. As was the case with the NEO-PI, Conscientiousness was not related to any of the preference scores; however, Leisure Activities, High Physical Effort Activities, and High Physical Risk Activities Preferences scores were related to the Adjective Checklist measure of Neuroticism.

Examination of the relations of the main effect preference scores with the facet scores on the NEO-PI suggest that the relations of the preference scores with Agreeableness are primarily a result of their relation with the facet of Compliance. For Extraversion, the relations appear to be a function of the relations with Gregariousness, Assertiveness, Activity, and Excitement-Seeking. The facets of Openness that appear to account for the significant relations with the preferences scores were Feelings, Ideas, Values, and Actions. While there were no significant relations with the domain scores on

Conscientiousness and Neuroticism, there were significant relations with the Deliberation facet of Conscientiousness and the Angry Hostility and Impusiveness facets of Openness.

Examination of the relations between the scores representing the two-way interactions based on the three factors of Presence of Others, Job Category, and Type of Risk and the personality measures, some differential relations appear. For example, while Solitary-Work and Solitary-Leisure Activities are both related to the Challenge dimension of Hardiness and Openness, Competitive-Work and Competitive-Leisure Activities Preferences are not related to the same personality measures. Competitive-Work Activities Preferences were significantly related to Control, Challenge, and Openness while Competitive-Work Activities were not significantly related to these same personality measures.

The pattern of results, therefore, support retaining the individual two-way interaction scores rather than collapsing these scores as suggested by the principle components analysis above. Also, as suggested in the literature, examination of the facets of personality rather than the five domains provides a somewhat clearer picture relations of between Activity Preferences and personality.

Scores Based on Target Activities Only
Correlation Coefficients between Personality Variables and Main Effects Variables

	ALON	SOCL	COMP	WORK	LEIS	PHYE	MENE	PHYR
Hardiness Scales								
Control	-.03	.07	.03	.13*	.10	.10	.15*	.12*
Commitment	-.09	.10	.14*	.05	.00	.04	.04	.00
Challenge	.22	.21	.04	.08	.23**	.15*	.20**	.20**
NEO-PI Domains								
Agreeableness	-.12*	.24**	-.12*	-.05	-.05	-.05	-.08	-.05
Conscientiousness	-.05	.05	-.00	.05	.00	.03	.03	.01
Extraversion	-.30**	.09	.17**	.18**	.25**	.23**	.24**	.27**
Neuroticism	.02	.02	-.04	.01	.04	.06	.00	.03
Openness	-.06	.13*	-.07	.03	.24**	.14*	.14*	.21**
Adjective Checklist								
Agreeableness	-.00	-.02	.01	-.03	.00	-.03	-.01	-.01
Conscientiousness	.04	-.04	.08	.08	-.02	.03	.04	.01
Extraversion	-.03	-.13*	-.17*	-.01	-.17**	-.10	-.11	-.13*
Neuroticism	.06	.09	.20*	.08	.14*	.16*	.09	.13*
Openness	.23	.05	.04	-.00	.17**	.06	.12*	.11

Correlation Coefficients between Personality Variables and Main Effects Variables (cont.)

	ALON	SOCL	COMP	WORK	LEIS	PHYE	MENE	PHYR
NEO-PI Facets								
Agreeableness Facets								
A1: Trust	-08	.09	-.07	-.06	.03	-.01	-.02	-.00
A2: Straightforwardness	-.11	.00**	-.21**	-.07	-.10	-.07	-.11	-.11
A3: Altruism	-.05	.04*	-.00	.03	-.01	-.00	.00	.01
A4: Compliance	-.11	0.13*	-.26	-.20**	-.16**	-.20**	-.18**	-.21**
A5: Modesty	-.06	-.01	-.22**	-.00	-.13*	-.07	-.09	-.08
A6: Tender-Mindedness	-.04	-.02	-.04	-.05	-.02	-.05	-.05	-.01
Conscientiousness Facets								
C1: Competence	.04	.00	.00	-.02	.04	-.00	.03	.01
C2: Order	.07	-.04	.08	.08	-.01	.04	.02	.01
C3: Dutifulness	.01	.11	.04	.06	.08	.10	.07	.06
C4: Achievement Striving	.11	.09	.10	.10	.11	.13*	.13*	.09
C5: Self-discipline	.07	.07	.02	.11	.03	.10	.07	.07
C6: Deliberation	-.12*	-.17**	-.11	-.11	-.17**	-.16*	-.14*	-.19**
Extraversion Facets								
E1: Warmth	-.03	.10	.10	.04	.07	.06	.05	.09
E2: Gregariousness	-.03	.16	.25**	.13*	.15*	.17**	.15*	.16*
E3: Assertiveness	.06**	.10	.24**	.05	.18**	.11	.15*	.15*
E4: Activity	.19**	.20**	.19**	.16**	.24**	.22**	.22**	.26**
E5: Excitement-Seeking	.16*	.24**	.40**	.27**	.31**	.30**	.32**	.36**
E6: Positive Emotions	.03*	.07	.08	.03	.07	.05	.05	.08
Neuroticism Facets								
N1: Anxiety	-.03	.02	.01	-.04	.01	.02	-.03	-.01
N2: Angry Hostility	.04	.02	.18**	.09	.07	.12*	.06	.08
N3: Depression	.04	.01	.06	.01	.06	.06	.03	.05
N4: Self-Consciousness	-.00	-.11	.05	.00	-.04	-.00	-.03	-.03
N5: Impulsiveness	.07	.06	.16*	.02	.15*	.10	.07	.14*
N6: Vulnerability	-.00	-.00	-.02	-.04	-.00	.00	-.05	-.01
Openness Facets								
O1: Fantasy	.09	.09	.09	-.02	.17**	.09	.05	.14*
O2: Aesthetics	.13*	.06	-.06	-.08	.12	.00	.02	.06
O3: Feelings	.16**	.19**	.20**	.08	.26**	.21**	.17**	.24**
O4: Actions	.12*	.15*	.00	.01	.15*	.08	.09	.12
O5: Ideas	.16*	.17**	.07	.07	.19**	.13*	.17**	.17**
O6: Values	.14*	.17**	.04	.03	.19**	.10	.13*	.17**

Note. * - Signif. LE .05; ** - Signif. LE .01 (2-tailed); ALON=Solitary, SOCL=Social, COMP=Competitive, WORK=Work, LEIS=Leisure, PHYE=Physical Effort, MENE=Mental Effort, PHYR=Physical Risk

Correlation Coefficients between Presence of Others by Job Category and Personality Variables

	WORK ALON	LEIS ALON	WORK SOCL	LEIS SOCL	WORK COMP	LEIS COMP
Hardiness Scales						
Control	.06	.03	.10	.06	.09	.14*
Commitment	-.00	-.09	.07	.05	.04	.03
Challenge	.18**	.22**	.11	.20**	-.11	.14*
NEO-PI						
Agreeableness	-.03	-.07	.01	.03	-.12*	-.10
Conscientiousness	.01	.06	.03	-.05	.06	.00
Extraversion	.02	.05	.10	.23**	.24**	.28**
Neuroticism	.02	-.00	-.04	.02	.09	.07
Openness	.14*	.18**	.01	.23**	-.05	.15*
Adjective Checklist						
Agreeableness	-.06	-.02	-.07	.01	.06	.00
Conscientiousness	-.00	.02	.03	-.09	.15*	.01
Extraversion	.03	-.04	.03	-.16*	-.10	-.17**
Neuroticism	.03	.02	.00	.12*	.15*	.16**
Openness	.12*	.27**	-.03	.06	-.06	.11
NEO-PI Facet Scores						
Agreeableness Facets						
A1: Trust	-.05	-.08	-.01	.13*	-.08	.00
A2: Straightforwardness	-.04	-.08	.03	-.01	-.17**	-.15*
A3: Altruism	-.06	-.07	.04	.03	.05	-.01
A4: Compliance	-.09	-.03	-.12	-.12	-.20**	-.19**
A5: Modesty	.03	-.08	.07	-.01	-.14*	-.21**
A6: Tender-Mindedness	-.04	-.02	-.03	-.01	-.04	-.01
Conscientiousness Facets						
C1: Competence	.00	.07	-.04	.00	.01	.04
C2: Order	.01	.03	.02	-.09	.13*	.02
C3: Dutifulness	-.00	.04	.07	.08	.04	.05
C4: Achievement Striving	.08	.12	.05	.07	.07	.09
C5: Self-Discipline	.04	.05	.13*	.02	.04	.01
C6: Deliberation	-.14*	-.06	-.08	-.20**	-.01	-.13*
Extraversion Facets						
E1: Warmth	-.03	-.08	.02	.12	.10	.09
E2: Gregariousness	-.06	-.09	.09	.16**	.22**	.23**
E3: Assertiveness	-.04	.08	-.01	.10	.18**	.22**
E4: Activity	.09	.20**	.12	.18**	.12*	.18**
E5: Excitement-Seeking	.04	.12*	.19**	.21**	.30**	.36**
E6: Positive Emotions	-.02	-.02	.00	.09	.08	.08

Correlation Coefficients between Presence of Others by Job Category and Personality Variables (cont.)

	WORK ALON	LEIS ALON	WORK SOCL	LEIS SOCL	WORK COMP	LEIS COMP
Neuroticism Facets						
N1: Anxiety	.00	-.05	-.07	.04	.00	.02
N2: Angry Hostility	.04	-.00	-.01	.02	.19**	.12*
N3: Depression	.03	.08	-.02	.02	.04	.05
N4: Self-Consciousness	.00	-.01	-.05	-.11	.08	.02
N5: Impulsiveness	-.00	.08	-.04	.10	.10	.17**
N6: Vulnerability	.03	-.03	-.04	.01	-.06	.00
Openness Facets						
O1: Fantasy	.05	.10	-.04	.15*	-.02	.16*
O2: Aesthetics	.07	.19**	-.06	.11	-.17**	.02
O3: Feelings	.08	.14*	.00	.22**	.11	.24**
O4: Actions	.09	.13*	.01	.17**	-.07	.05
O5: Ideas	.12*	.17**	.07	.17**	-.03	.13*
O6: Values	.11	.14*	.0551	.18**	-.08	.12

Note. * - Signif. LE .05; ** - Signif. LE .01 (2-tailed); WORK=Work Activities, LEIS=Leisure Activities; ALON=Solitary, SOCL=Social, COMP=Competitive; PHYE=Physical Effort, MENE=Mental Effort, PHYR=Physical Risk

Correlation Coefficients between Presence of Others by Risk and Personality Variables

	PHYE ALON	MENE ALON	PHYR ALON	PHYE SOCL	MENE SOCL	PHYR SOCL	PHYE COMP	MENE COMP	PHYR COMP
Hardiness Scales									
Control	.04	.05	.06	.06	.12	.10	.12	.16**	.10
Commitment	-.05	-.06	-.05	.06	.07	.07	.05	.06	-.00
Challenge	.18**	.22**	.27**	.14*	.19**	.20**	.03	.04	.02
NEO-PI									
Agreeableness	-.09	-.07	-.01	.04	.00	.03	-.11	-.13*	-.13*
Conscientious-ness	.04	.04	.04	-.02	.00	-.01	.06	.03	.01
Extraversion	.01	.04	.05	.17**	.20**	.19**	.28**	.30**	.32**
Neuroticism	.01	.03	-.01	.00	-.03	-.01	.12*	.03	.10
Openness	.14*	.15*	.24**	.12	.14*	.16*	.07	.04	.09
Adjective Checklist									
Agreeableness	-.07	-.04	-.02	-.04	-.04	-.02	.01	.05	.02
Conscientious-	.00	.04	-.01	-.03	-.02	-.03	.09	.08	.07
Extraversion	.01	.01	-.03	-.05	-.09	-.05	-.16**	-.18**	-.17**
Neuroticism	.07	.03	-.00	.07	.04	.08	.20**	.12*	.21**
Openness	.19**	.20**	.28**	-.01	.02	.02	.01	.09	.00

Correlation Coefficients between Presence of Others by Risk and Personality Variables (cont.)

	PHYE ALON	MENE ALON	PHYR ALON	PHYE SOCL	MENE SOCL	PHYR SOCL	PHYE COMP	MENE COMP	PHYR COMP
NEO-PI Facet Scores									
Agreeableness Facets									
Trust	-.11	-.09	-.02	.06	.05	.06	-.04	-.03	-.05
Straightforward-ness	-.08	-.09	-.05	.04	-.01	.01	-.15*	-.18**	-.22**
Altruism	-.11	-.10	-.03	.05	.04	.03	.01	.03	.01
Compliance	-.09	-.08	-.03	-.11	-.14*	-.15*	-.22**	-.19**	-.25**
Modesty	-.05	-.03	-.00	.05	.00	.04	-.19**	-.20**	-.21**
Tender-Minded-ness	-.10	-.04	.01	-.00	-.04	-.02	-.03	-.02	-.02
Conscientiousness Facets									
Competence	.01	.03	.06	-.04	-.00	-.02	.03	.05	.01
Order	.04	.02	.00	-.02	-.02	-.05	.09	.07	.08
Dutifulness	.01	.00	.04	.08	.10	.08	.10	.05	.01
Achievement Striving	.11	.12	.12	.06	.09	.06	.14*	.09	.04
Self-Discipline	.07	.03	.06	.09	.10	.07	.05	.03	.01
Deliberation	-.11	-.12	-.11	-.16**	-.14*	-.17**	-.07	-.07	-.13*
Extraversion Facets									
Warmth	-.09	-.09	-.03	.09	.06	.08	.09	.12	.13*
Gregariousness	-.09	-.07	-.09	.16**	.14*	.12*	.25**	.26**	.27**
Assertiveness	-.01	.02	.06	.02	.07	.05	.22**	.27**	.20**
Activity	.15*	.14*	.20**	.14*	.18**	.19**	.20**	.17**	.17**
Excitement Seeking	.08	.13*	.07	.20**	.26**	.23**	.35**	.33**	.45**
Positive Emotions	-.04	-.03	-.00	.06	.05	.04	.07	.08	.13*
Neuroticism Facets									
Anxiety	-.02	-.01	-.03	.00	-.04	-.02	.05	-.02	.01
Angry Hostility	.06	.01	-.00	.02	-.01	.00	.20**	.14*	.18**
Depression	.07	.08	.06	.00	-.02	.01	.07	.02	.05
Self-Conscious-ness	.00	.02	-.03	-.07	-.11	-.10	.06	.03	.06
Impulsiveness	.00	.06	.07	.06	.00	.02	.14*	.12	.21**
Vulnerability	.02	-.00	-.01	-.00	-.04	-.01	-.01	-.07	-.01
Openness Facets									
Fantasy	.07	.06	.11	.05	.04	.05	.08	.03	.15*
Aesthetics	.10	.11	.22**	.00	.02	.04	-.07	-.06	-.07
Feelings	.11	.08	.18**	.12	.11	.12*	.23**	.19**	.22**
Actions	.07	.09	.19**	.11	.09	.11	.00	.02	-.02
Ideas	.15*	.13*	.21**	.09	.16**	.15*	.06	.09	.04
Values	.10	.11	.21**	.10	.14*	.15*	.02	.04	.03

Note. * - Signif. LE .05; ** - Signif. LE .01 (2-tailed); WORK=Work Activities, LEIS=Leisure Activities; ALON=Solitary, SOCL=Social, COMP=Competitive; PHYE=Physical Effort, MENE=Mental Effort, PHYR=Physical Risk

Correlation Coefficients between Job Category by Risk Variables and Personality Variables

	PHYE WORK	MENE WORK	PHYR WORK	PHYE LEIS	MENE LEIS	PHYR LEIS
Hardiness Scales						
Control	.09	.13*	.14*	.09	.13*	.08
Commitment	.06	.05	.04	.02	.02	-.02
Challenge	.04	.08	.12	.20**	.26**	.22**
NEO-PI						
Agreeableness	-.03	-.07	-.04	-.05	-.06	-.04
Conscientiousness	.02	.05	.07	.02	.00	-.03
Extraversion	.15*	.19**	.18**	.22**	.23**	.27**
Neuroticism	.03	.02	-.00	.06	-.00	.06
Openness	.00	.02	.08	.21**	.22**	.26**
Adjective Checklist						
Agreeableness	-.03	-.02	-.03	-.02	.00	.01
Conscientiousness	.07	.10	.07	-.00	-.02	-.03
Extraversion	.01	-.02	-.04	-.15*	-.17**	-.16**
Neuroticism	.11	.08	.04	.15*	.08	.17**
Openness	-.05	-.01	.05	.13*	.22**	.13*
NEO-PI Facet Scores						
Agreeableness Facets						
A1: Trust	-.04	-.08	-.06	.01	.04	.04
A2: Straightforwardness	-.05	-.09	-.06	-.07	-.10	-.12*
A3: Altruism	.02	.01	.04	-.03	-.01	-.01
A4: Compliance	-.17**	-.21**	-.19**	-.16**	-.12	-.18**
A5: Modesty	.00	-.02	.00	-.12	-.13*	-.13*
A6: Tender-Mindedness	-.05	-.06	-.04	-.04	-.02	.00
Conscientiousness Facets						
C1: Competence	-.05	-.01	.00	.03	.06	.02
C2: Order	.06	.09	.08	.01	-.03	-.03
C3: Dutifulness	.05	.05	.08	.11	.08	.02
C4: Achievement Striving	.07	.10	.11	.15*	.13*	.05
C5: Self-Discipline	.11	.09	.13*	.06	.04	.00
C6: Deliberation	-.11	-.11	-.10	-.15*	-.14*	-.21**
Extraversion Facets						
E1: Warmth	.07	.03	.03	.04	.05	.11
E2: Gregariousness	.15*	.13*	.09	.14*	.13*	.17**
E3: Assertiveness	.00	.06	.09	.16**	.20**	.15*
E4: Activity	.11	.15*	.21**	.24**	.21**	.23**
E5: Excitement Seeking	.24**	.29**	.24**	.26**	.27**	.36**
E6: Positive Emotions	.03	.03	.02	.05	.05	.11
Neuroticism Facets						
N1: Anxiety	-.00	-.04	-.06	.04	-.01	.02
N2: Angry Hostility	.11	.08	.07	.10	.02	.07
N3: Depression	.02	.01	.01	.08	.03	.07
N4: Self-Consciousness	.03	.00	-.03	-.03	-.06	-.02
N5: Impulsiveness	.02	.01	.01	.12*	.10	.21**
N6: Vulnerability	-.01	-.05	-.06	.01	-.04	.02

Correlation Coefficients between Job Category by Risk Variables and Personality Variables (cont.)

	PHYE WORK	MENE WORK	PHYR WORK	PHYE LEIS	MENE LEIS	PHYR LEIS
Openness Facets						
O1: Fantasy	-.01	-.03	-.02	.14*	.12	.24**
O2: Aesthetics	-.11	-.10	-.02	.09	.13*	.12
O3: Feelings	.07	.05	.11	.25**	.23**	.28**
O4: Actions	-.02	-.00	.07	.14*	.15*	.13*
O5: Ideas	.03	.06	.12*	.16**	.22**	.16**
O6: Values	-.00	.02	.08	.15*	.20**	.19**

Note. * - Signif. LE .05; ** - Signif. LE .01 (2-tailed); WORK=Work Activities, LEIS=Leisure Activities; ALON=Solitary, SOCL=Social, COMP=Competitive; PHYE=Physical Effort, MENE=Mental Effort, PHYR=Physical Risk

The activities included in the experimental Activity Preference Inventory were selected such that there were no significant gender or race differences in perceptions of physical effort, mental effort, and physical risk. However, preference scores could still result in gender or race differences as was suggested by significant differences on the proportion of activities by Presence of Others and Job Category across target and non-target activities presented above.. Therefore, the correlations of the scores based on target activities only on the Activity Preference Inventory with age, gender and race were computed and are presented below. Of the main effect variables, all but one (Solitary Acclivities Preferences) were significantly related to age with younger respondents tending to prefer a greater proportion of the target items. Similarly, there were significant relations with gender for Social Activities, Leisure Activities, High Physical Effort, and High Mental Effort Preferences such that men tended to prefer a greater proportion of the target items. There were no gender differences on Solitary Activities, Competitive Activities, Work Activities, and High Physical Risk Activities Preferences. These gender differences appear to result from High Physical Effort-Solitary Activities, High Physical Effort-Social Activities, High Mental Effort-Solitary Activities, High Mental Effort-Social Activities, High Physical Effort-Leisure Activities, and High Mental Effort-Leisure Activities. Race was significantly related to all of the main effect preference scores as well as all but two of the two-way interaction preference scores, those being Competitive-Work Activities and Competitive-High Mental Effort Activities Preferences. When one examines the correlations of the personality measures with age, gender, and race, it is readily apparent that there are substantially fewer correlations suggesting that the activity preference scores may reflect other cultural and social aspects of the respondents.

Correlation Coefficients between Demographic Variables and Experimental Variables

	Age	Gender	Race
Presence of Others			
Solitary	-.00	-.12	.28**
Social	-.13*	-.14*	.45**
Competitive	-.25**	-.05	.19**
Job Category			
Work	-.16*	-.09	.22**
Leisure	-.13*	-.14*	.41**
Risk			
Physical Effort	-.18**	-.14*	.38**
Mental Effort	-.13*	-.15*	.33**
Physical Risk	-.16**	-.10	.37**
Presence of Others by Job Category			
WORKALON	.05	-.12*	.26**
LEISALON	.04	-.13*	.22**
WORKSOCL	-.09	-.11	.21**
LEISSOCL	-.13*	-.12*	.44**
WORKCOMP	-.25**	.04	-.02
LEISCOMP	-.19**	-.08	.28**
Presence of Others by Risk			
PHYEALON	.00	-.21**	.23**
MENEALON	.03	-.13*	.25**
PHYRALON	.11	-.11	.32**
PHYESOCL	-.11	-.12*	.38**
MENESOCL	-.14*	-.16**	.37**
PHYRSOCL	-.14*	-.12	.36**
PHYECOMP	-.27**	-.02	.23**
MENECOMP	-.19**	-.05	.12
PHYRCOMP	-.28**	-.01	.17**
Job Category by Risk			
PHYEWORK	-.17**	-.11	.19**
MENEWORK	-.16**	-.07	.19**
PHYRWORK	-.11	-.08	.24**
PHYELEIS	-.15*	-.13*	.43**
MENELEIS	-.07	-.18**	.37**
PHYRLEIS	-.15*	-.09	.38**

Note. * - Signif. LE .05; ** - Signif. LE .01 (2-tailed); WORK=Work Activities, LEIS=Leisure Activities; ALON=Solitary, SOCL=Social, COMP=Competitive; PHYE=Physical Effort, MENE=Mental Effort, PHYR=Physical Risk

Correlation Coefficients between Demographic Variables and Personality Variables	Age	Gender	Race
Hardiness Scales			
Control	-.01	.03	-.02
Commitment	-.04	.12*	.01
Challenge	.15*	-.12*	.14*
NEO-PI Domains			
Agreeableness	.16**	.15*	.08
Conscientiousness	.07	.06	-.05
Extraversion	-.06	.06	.13*
Neuroticism	-.15*	.15*	.12
Openness	-.00	.04	.20**
Adjective Checklist			
Agreeableness	-.05	.17**	-.11
Conscientiousness	-.04	.07	-.20**
Extraversion	-.05	-.04	-.08
Neuroticism	-.19**	.01	.17**
Openness	.20**	-.02	.06
NEO-PI Facets			
Agreeableness Facets			
A1: Trust	.15*	.05	.12*
A2: Straightforwardness	.20**	.17**	.06
A3: Altruism	.04	.25**	.00
A4: Compliance	.16*	-.01	-.02
A5: Modesty	.11	.10	.00
A6: Tender-Mindedness	.03	.20**	-.07
Conscientiousness Facets			
C1: Competence	.16**	.06	-.12*
C2: Order	-.07	.00	-.01
C3: Dutifulness	.15*	.05	.08
C4: Achievement Striving	.06	-.01	-.01
C5: Self-Discipline	.03	.00	-.03
C6: Deliberation	.05	.08	-.11
Extraversion Facets			
E1: Warmth	.05	.14*	.11
E2: Gregariousness	-.10	.06	.02
E3: Assertiveness	.00	.05	-.07
E4: Activity	.05	-.08	.23**
E5: Excitement-Seeking	-.30**	-.08	.04
E6: Positive Emotions	-.02	.07	.03
Neuroticism Facets			
N1: Anxiety	-.20**	.21**	.11
N2: Angry Hostility	-.18**	.03	.10
N3: Depression	-.12	.05	.06
N4: Self-Consciousness	-.10	.07	-.06
N5: Impulsiveness	-.07	.13*	.11
N6: Vulnerability	-.10	.10	.13*

Correlation Coefficients between Demographic Variables and Personality Variables (cont.)

	Age	Gender	Race
Openness Facets			
O1: Fantasy	-.08	-.03	.16*
O2: Aesthetics	.09	.12	.06
O3: Feelings	-.08	.10	.13*
O4: Actions	.14*	.09	.11
O5: Ideas	.02	-.14*	.11
O6: Values	.14*	.03	.20**

Note. * - Signif. LE .05; ** - Signif. LE .01 (2-tailed); Gender: 1=men, 2=women; Race: 1=African-American, 2=Other

Summary

The purpose of this project was to develop an experimental version of the Activity Preference Inventory to serve as the next generation of the Activity Interest Inventory. It was suggested by a review of the literature and an examination of the Activity Interest Inventory, that Presence of Others, Work versus Leisure Activities, and degree of Physical Effort, Mental Effort, and Physical Risk would affect individuals preferences among activities. Construction of an Activity Preference Inventory systematically varying these factors confirmed the hypotheses. Further, the data suggested interactions between the factors.

Taking into account the dimensions built into the Activity Preference Inventory, the data support that the experimental version had satisfactory internal consistency as well as sufficient discriminability among the activities. While the scores were moderately to strongly correlated and a factor analysis suggested four underlying dimensions of Competitive Activity Preference, Solitary Activity Preference, Social Leisure Activity Preference, and Social Work Activity Preference, differential relations with various aspects of personality were obtained justifying the retention of the individual preference scores.

The preference scores generally were found to be related to all three dimensions of Hardiness (Control, Commitment, and Challenge) as well as three of the personality domains measured by the NEO-PI (Agreeableness, Extraversion, and Openness). While there were no significant relations with the domain scores on Conscientiousness and Neuroticism, there were some significant relations with the facet scores for these domains. Deliberation and to a lesser extent Achievement Striving in the Conscientiousness domain and Angry Hostility and Impulsiveness in the Neuroticism domain were related to some of the activity preference scores. These results differ somewhat with the relations of the previous Activities Interest Inventory that was found to be negatively related to Neuroticism and positively related to Extraversion. It is possible that these differences are due to different measures of personality used in the prior research which is partially supported by the different relations observed for the experimental Activities Preference Inventory and the two measures of the five domains of personality used in this study.

While the data from this study indicate that the scores on the experimental Activity Preference Inventory were correlated with established personality characteristics, the data support the notion that risk-taking preferences are not subsumed within any particular personality domain or facet. Rather the pattern of results support that risk-taking attitudes, as measured by this newly developed instrument, are related to several personality characteristics that have been shown to differentiate successful pilots. For example, Deitz and Johnson (1991), in their summary of the relations between personality characteristics and pilot performance, reported that successful pilots tended to be bright, sociable, self-sufficient, imaginative, and high on exhibition, dominance, aggression, consistency, and achievement motivation and low on affiliation, nurturance, succorance, order, and autonomy. Similarly, hazardous pilots tended to be characterized as antiauthority, impulsive, invulnerable, and externally controlled. Scores on the experimental inventory were found to be related to most of these characteristics. Thus, the pattern of relations of scores obtained on this experimental instrument are consistent with the literature on pilot performance and provide some evidence of the construct validity of the experimental Activity Preference Inventory.

In addition to being related to dimensions of personality, scores on the experimental Activity Preference Inventory were found to be related to age, race, and gender. Further, these relations were stronger than the relations among the personality measures and age, race, and gender. These findings suggest that activity preferences may be a function of other aspects in the environment than just personality which is consistent with earlier findings in this project that familiarity and experience with activities is related to the perception of the degree of risk involved in the activities. Clearly, further research should be undertaken to examine whether the differences based on age, race, and gender can be eliminated by inclusion of different activities.

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Abstract

The seasonal distribution and bionomics of the imported Asian tiger mosquito, *Aedes albopictus* (Skuse), in central Georgia was investigated by a 15 month study within an area extending from a 50 km radius of Macon, Georgia. Aspects of this project included the determination of the relative abundance of tree hole developing mosquitoes within the study area, and in particular, the larval frequency of the Asian tiger mosquito in tree holes. A total of 1,961 mosquito larvae were recovered from 47 urban, suburban, or sylvatic tree holes from 15 tree species. Quantitative ovitrapping and a qualitative survey of selected tree holes for bacterial microflora were also completed.

Additional sampling beyond the study region also increased the total number of positive counties in Georgia for *Aedes albopictus* to 155. Four counties remain to be sampled during the adult mosquito season of 1994.

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INTRODUCTION

The establishment of the imported Asian tiger mosquito, *Aedes albopictus* (Skuse) in the United States has produced concern with public health officials as this species can serve as a vector for many endemic and exotic viruses. Laboratory investigations have demonstrated the capability of this vector to transmit Venezuelan equine encephalomyelitis (Beaman & Turell 1991), Chikungunya virus (Turell et al. 1992), La Crosse virus (Grimstad et al. 1989), and Rift Valley Fever (Turrell et al. 1988). This mosquito is also capable of transmitting the viruses for Japanese encephalitis, yellow fever, West Nile, Ross River, 4 serotypes of dengue, St. Louis encephalitis, and western equine encephalitis (Shroyer 1986). In 1991, strains of eastern equine encephalitis virus were isolated from adult *Ae. albopictus* in Florida (Mitchell et al. 1992).

Aedes albopictus was first discovered in 1985 in Harris County, Texas (Sprenger & Wuithiranyagool 1986). Used tire importation from northern Asia is now accepted as the source of importation into this country (Hawley et al. 1987). A single female specimen collected in Memphis, Tennessee in 1983 may have originated from the Texas focus that had become well established prior to 1983 (Craven et al. 1988). Since its introduction in Texas, this species has increased its range throughout the southeastern and midwestern states. It is the principal nuisance mosquito in many metropolitan areas. Also, in most of its range it has been reported to seriously reduce the prevalence of another mosquito, *Aedes aegypti* (Linn.) which also shares the same artificial container larval habitat that *Ae. albopictus* can utilize. In many parts of the southeast, *Ae. aegypti* is difficult to recover if *Ae.*

albopictus is abundant (Francy et al. 1990).

Aedes albopictus was first reported in Macon, Georgia in the summer of 1991. Prior to that year, only 5 counties in Georgia had reported infestations. Additional collections since then have increased the total number of confirmed counties in the state to 155 of 159 Georgia counties. Most state mosquito control authorities expect that all counties within Georgia have some degree of infestation for this imported mosquito.

In its native Asian habitat, this species completes larval development in tree holes in forested areas. At the time of this project, limited published research existed on the frequency of this mosquito in tree holes in Georgia. Consequently, a survey of tree holes for this imported species was considered necessary to delineate the bionomics of this mosquito in this area. This report describes the results of a 15 month investigation into the seasonal abundance, distribution, and bionomics of Ae. albopictus in the suburban and urban woodlands of central Georgia.

MATERIALS AND METHODS

Adult Prevalence

Observations within the study area for Ae. albopictus (Figure 1) which includes all or portions of Baldwin, Bleckley, Bibb, Butts, Crawford, Houston, Jasper, Jones, Lamar, Macon, Monroe, Peach, Putnam, Taylor, Twiggs, Upson, and Wilkinson counties by public health authorities were limited prior to 1991. Preliminary surveys in 1991 and 1992 indicated that Ae. albopictus was present to some degree in the environs of Macon, but no data were available for surrounding communities such as Milledgeville, Warner Robins, or Fort Valley. As this species is not readily attracted by entomological light trapping methods, this study utilized a standard procecure for monitoring prevalence of adult mosquitoes, an adult ovitrap. The traps consisted of a 0.50 liter, 11.5 cm high plastic novelty cup (Louisiana Plastics Inc., St. Louis, MI). A wooden tongue

depressor covered with brown paper toweling secured with a metal staple served as an ovipaddle. Forty-eight students, staff, and faculty of Macon College (Appendix 1) volunteered to establish traps at their residences during the April through November, 1993 sampling period. These sampling sites were distributed within the 50km area of the project study. Each participant was instructed to partially fill the traps with water and place them in shaded areas within 1 meter of the ground at their residence. The ovipaddles were returned weekly for analysis and replaced with a new ovipaddle. Ovipaddles were processed by counting the total number of Aedes species ova present, and embryonating them in an incubator at 80°C and 80% humidity for 5 days. Ova were hatched and larvae reared on a diet of liver powder at 27.5°C and a photoperiod of 14/10 hours in an environmental incubator (Precision Scientific Co.). to the adult stage for positive identification. The number of male and female individuals of each mosquito species were recorded and the ovitrapping results are found in Figure 2.

Tree Hole Investigations

Beginning in January, 1993 public access lands in the study area were surveyed for possible tree holes which could support larval mosquito development. Forty-seven tree holes were selected from urban, suburban, and sylvatic habitats. Tree species included Sweetgum, Liquidambar styraciflua L. (14 sites; Red Maple, Acer rubrum L (5 sites); Hackberry, Sugarberry, Celtis laevigata Willd. (7 sites); Southern Magnolia, Magnolia grandiflora L. (5 sites); Black Gum, Nyssa sylvatica Marshall (3 sites); and Southern Red Oak, Quercus falcata Michaux; (2 sites). The remaining tree species comprised 1 tree hole per tree species. These were Yellow Poplar, Liriodendron tulipfera L; White Oak, Quercus alba L.; Live Oak, Quercus virginiana Miller; Water Oak, Quercus nigra L.; Willow Oak, Quercus phellos L.; Winged Elm, Ulmus alata Michaux; Flowering Dogwood, Cornus florida L.; Pecan, Carya illinoensis (Wang.) K. Koch; and Wild Plum, Prunus americana Marshall. Photographic records were made of each tree hole to facilitate

field identification on subsequent sampling visits. Temperature and rainfall data were obtained from National Weather Service records at the Macon Regional Airport.

Tree holes were visited monthly beginning in January, 1993 and within 1 week of any significant rainfall for a specific area during the study period. Larvae were collected with a turkey baster and returned to the laboratory for positive identification and counting. First and second instar mosquito larvae were reared to later stages on liver powder and a 14/10 photoperiod for positive identification. Larvae were identified according to Carpenter and LaCasse (1957), Ae. albopictus according to Darsie (1986). Records were maintained for total productivity and mosquito species for each tree hole. Statistics were computed with the MiniTab Statistical Package, Minitab, Inc.

Bacteriological Sampling

Selected tree species were chosen for bacteriological sampling. Before larvae were collected from a tree hole, a 10ml water sample was taken with a sterile pipette and placed in a sterile water bottle. Bacteria were plated out in the laboratory on tryptic soy agar. Isolated pure cultures were selected for identification. Gram negative bacterial cultures were analyzed with the API 20e rapid identification system (Analytab Products). Further confirmation of identity was obtained from a commercial diagnostic facility, Doctor's Laboratory Inc., Valdosta, Georgia. Gram positive bacteria were identified to genus by the same commercial laboratory.

Survey of Georgia

During this study, additional sampling for adult Asian tiger mosquito activity in previously unsampled Georgia counties was accomplished. Tire resellers, cemeteries, and roadside parks were selected as ideal potential sites for collection. Adult mosquitoes were collected with a battery operated hand aspirator. A landing/biting collection was used. Voucher specimens for each new county record were placed in the entomology collection of Macon College.

RESULTS

Adult Study

Container breeding mosquitoes began their 1993 adult activity in early April. The ovitrapping study resulted in 119/148 positive ovipaddles and the collection of 6,535 ova. Of these Ae. albopictus was the most dominant species as all positive ovipaddles included this species. Nineteen paddles were positive for both Ae. albopictus and Aedes triseriatus, (Say) another container breeding mosquito. Two paddles were positive for Ae. aegypti and Ae. triseriatus. The former is a species formerly dominant in the artificial container breeding niche. Orthopodomyia signifera (Coq.) was found on 1 ovipaddle.

Tree Hole Investigations

Forty-seven tree holes were sampled in the 1993. Only 31 of these produced mosquito larvae during the survey period. Precipation in the study area (Figure 3), a critical element of the tree hole niche, was low during the summer of 1993. This rainfall deficit also decreased the total number of samples recovered from each tree hole site. Maximum and mininum temperatures and photoperiod data are found in Figures 4 and 5, respectively.

Seven sites lacked infestation with Ae. albopictus but other tree hole mosquito larvae such as Ae. triseriatus, Or. signifera, and Toxorhynchites rutilis septentrionalis (Dyar and Knab) were present. Twenty-four tree holes produced some degree of infestation along with the presence of normally expected conspecific tree hole mosquito larvae. This represents 77.41 per cent of larvae producing tree holes. At the end of March, 1994, 1,961 tree hole mosquito larvae were recovered from 31 tree holes. The monthly summary of collected larvae for 1993 and 1994 and the monthly percentage of Ae. albopictus is presented in Figures 6 & 7. The overall

incidence for Ae. albopictus was 20.75 per cent in tree holes for the 15 month period. Ae. triseriatus followed with a per cent incidence of 73.58 per cent. Other tree hole species included Or. signifera, at 1.58 per cent; Tx. rutilis septentrionalis, 0.459 per cent and Culex pipiens Linn. with 3.62 per cent. In Table 1. are found the results of the tree hole survey with the percentage of Ae. albopictus infestation for each tree hole.

Bacteriological Sampling

By the end of March, 1994 a total of 23 bacterial cultures isolated from tree holes were identified. Bacteria include members of the following genera, Alcaligenes, Bacillus, Pseudomonas, Moraxella and Yersinia. Species of Pseudomonas predominated as they comprised 60.87 per cent of the identified cultures.

State Survey

Forty-eight previously unreported counties were proved infested with the Asian tiger mosquito by this project in 1993 (Figure 8). Additional 1993 sampling by other collectors within Georgia increased the total number of infested counties to 156. Only 4 counties remain to be surveyed in Georgia during 1994. These are Dade, Fannin, Union, and Towns. State mosquito control authorities suspect that all 159 counties have varying degrees of infestation for Ae. albopictus. Table 2 indicates the new county records and cities for the Asian tiger mosquito contributed by this project.

DISCUSSION

Adult Study

Adults of Ae. triseriatus appeared in early-March; however, the first spring Ae. albopictus adult specimens were collected in 1993 and 1994 in late March. Although not in any great abundance, the latter gradually increased their numbers throughout the summer until they became the primary complaint mosquito for central Georgia residents. The tendency of the mosquito to occur as a peridomestic species was accurately demonstrated in

this study in that all positive ovitraps were at private residences. Ae. albopictus adults were collected from April through October in urban, suburban, and sylvatic, habitats throughout the 50 km diameter study area of central Georgia. The first hard freeze in October, 1993 ended the adult activity until March of 1994.

Larval Study

The imported strain of Ae. albopictus produces eggs in late summer which diapause during the winter months in northern latitudes. However, the strain found in central Georgia behaved in this regard more like the non-diapausing strain reported from Florida. No evidence was seen of any egg diapause in central Georgia in this investigation. That is, a small number of late summer produced eggs continued to hatch throughout the winter months producing 4th instar larvae which did not pupate until March. These data suggest a larval diapause similar to Ae. triseriatus. Kappus and Venard (1967) reported that an Alabama strain of Ae. triseriatus had a larval photoperiod requirement of 12-13 hours of light for pupation.

Or. signifera larvae were not as abundant as expected, and their low representation in this study require further investigation. These data suggest that an interspecific interaction between Ae. albopictus and Or. signifera may be reducing the expected numbers of the latter species.

As shown by Figure 7, Ae. triseriatus overwinters as 4th instar larvae and was the species most commonly recovered in this study from November to July. Ae. albopictus was the second most common species and reached its greatest larval prevalence from August through October. However, larvae of both species could be commonly recovered together in relatively large numbers from tree holes during the summer months. This marks the time of greatest larval competition.

Figure 9 illustrates an interspecific association between these two species. This scatter plot, comprised of the numbers of each larvae for all 31 positive sites against each other, has a positive regression line. A

correlation of 0.47 suggests that these two species are not mutually exclusive and can be expected to be found together. The low numbers of *Or. signifera* precluded a statistical correlation with *Ae. albopictus*. The number of the predaceous larvae of *Tx. rutilus septentrionalis* were in accordance with expected numbers for this species.

CONCLUSIONS

Ae. albopictus was the predominant peridomestic mosquito breeding in artificial containers in the geographic area of this study with a prevalence of 100 per cent. In natural tree holes, this species achieved an overall incidence of 21 per cent. The Asian tiger mosquito shares the tree hole niche with *Ae. triseriatus*, another tree hole mosquito, with little apparent competition. *Ae. albopictus* did not exhibit a definitive egg diapause during this 15 month study; the species coexists during the winter months in low numbers as 4th instar larvae along with diapausing larvae of *Ae. triseriatus*.

Adult *Ae. albopictus* gradually increased their numbers from late March to early April in both the spring of 1993 and 1994. By late summer, it was the principal peridomestic mosquito in central Georgia. The invasion and establishment of this imported disease vector into native deciduous tree holes presents a difficult challenge for pest management authorities.

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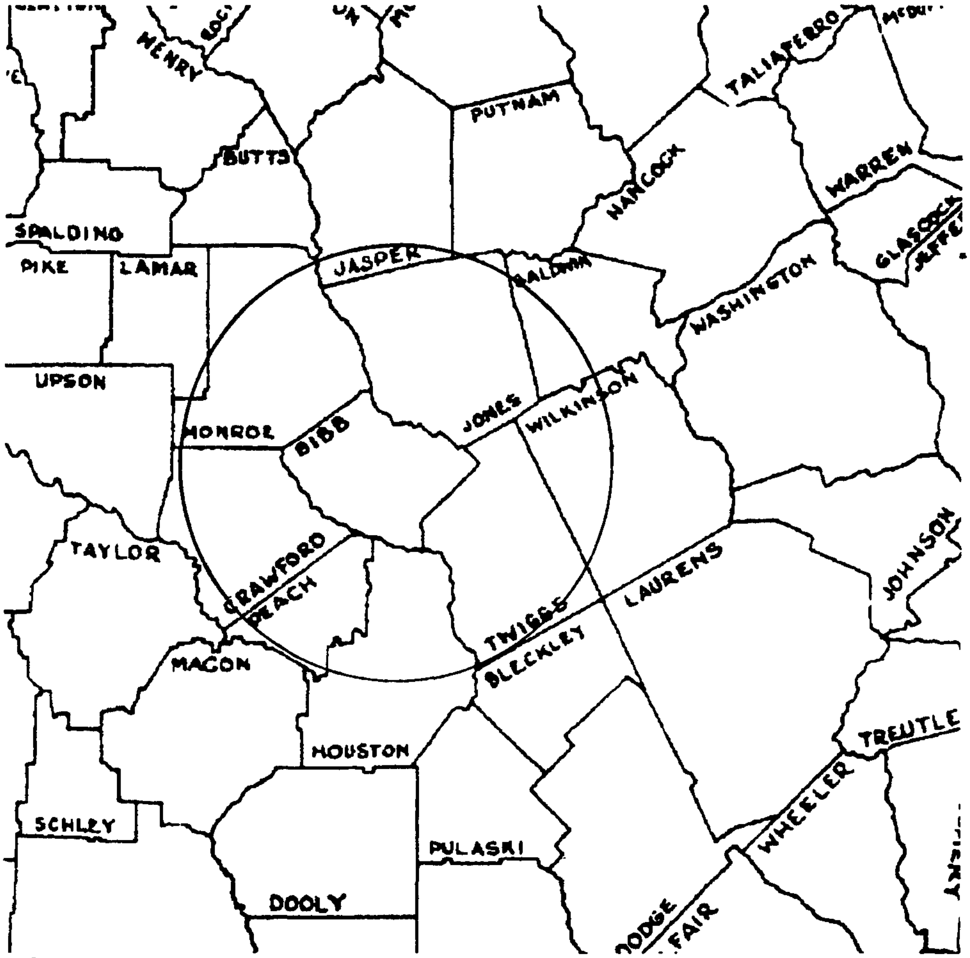

Figure 1. Central Georgia Collecting Area.

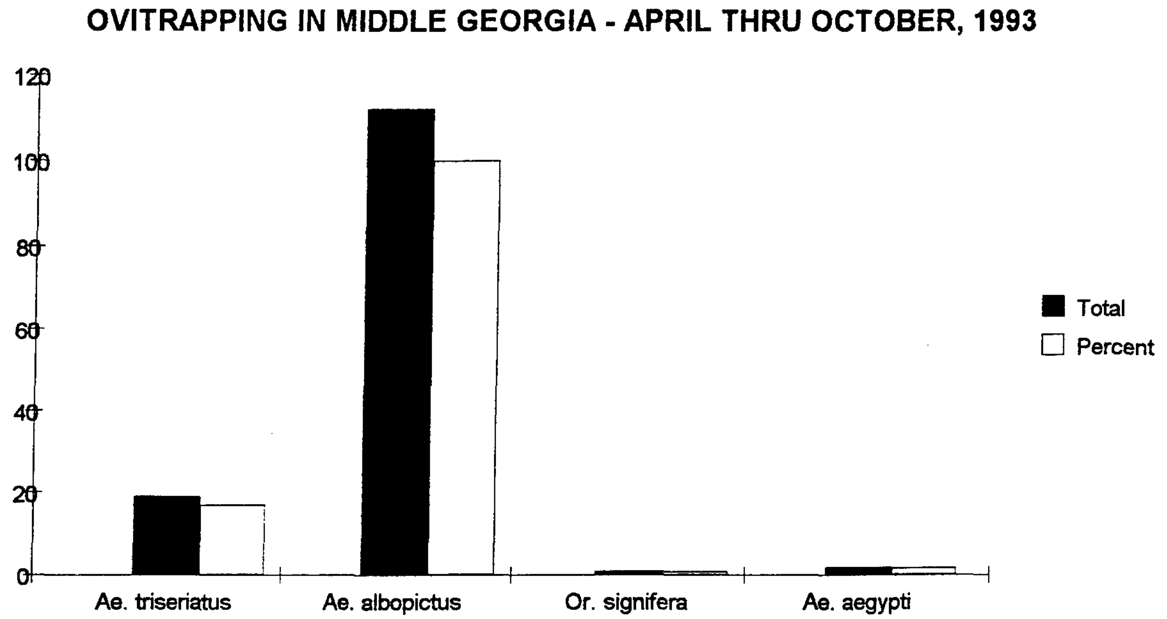

Fig. 2. Species and Per Cent of Positive Ovipaddles

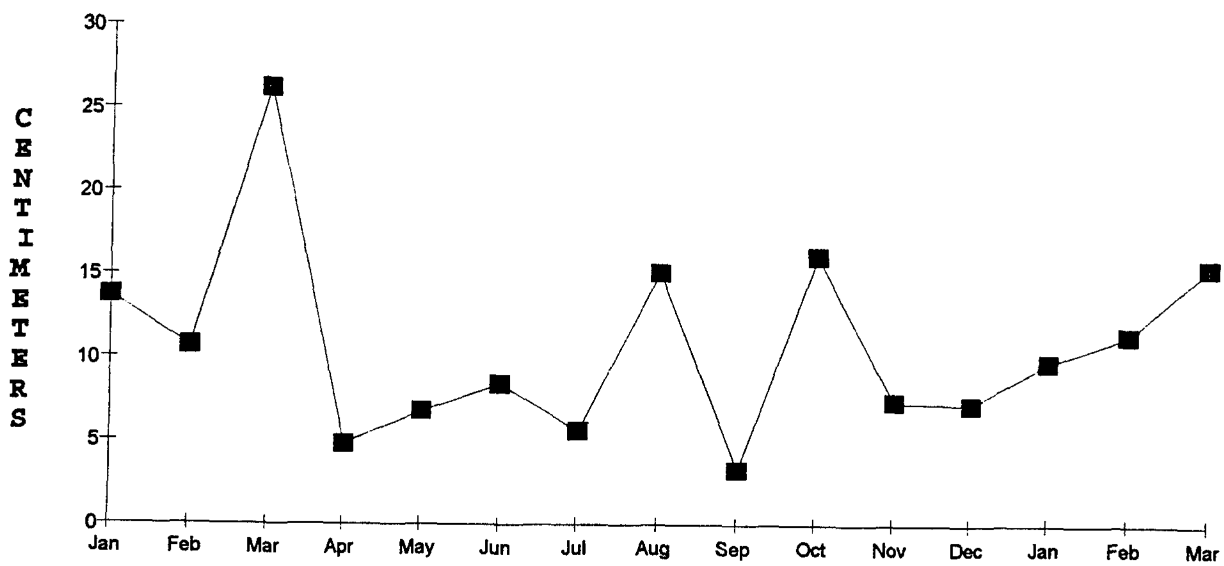

Fig. 3. Monthly Precipation, 1993 - 1994

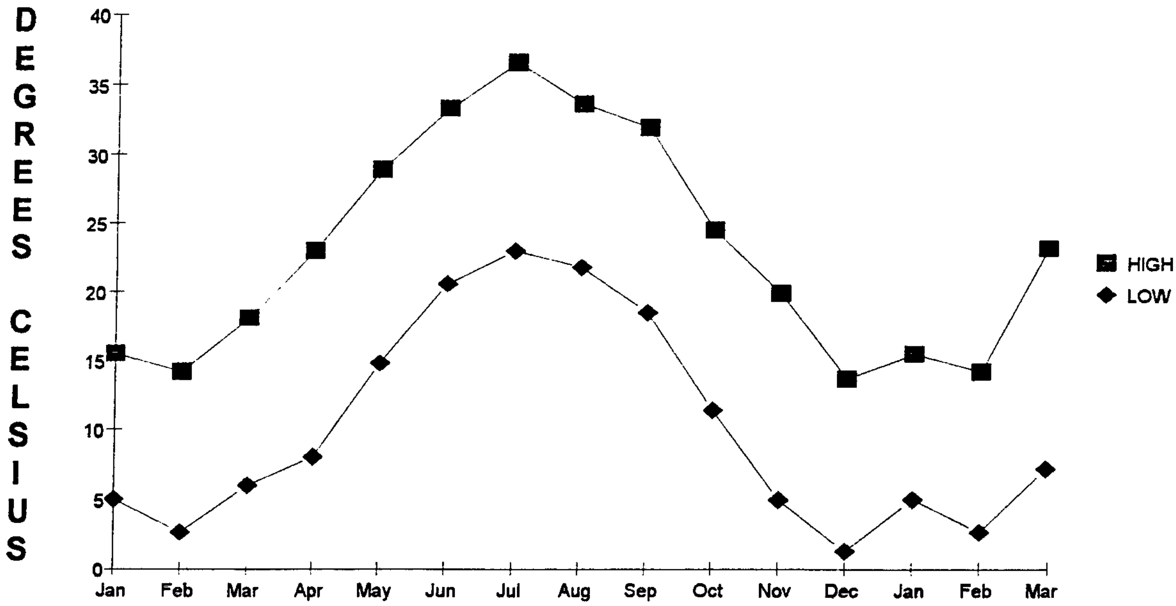

Fig. 4 Monthly Mean Temperatures, 1993 - 1994

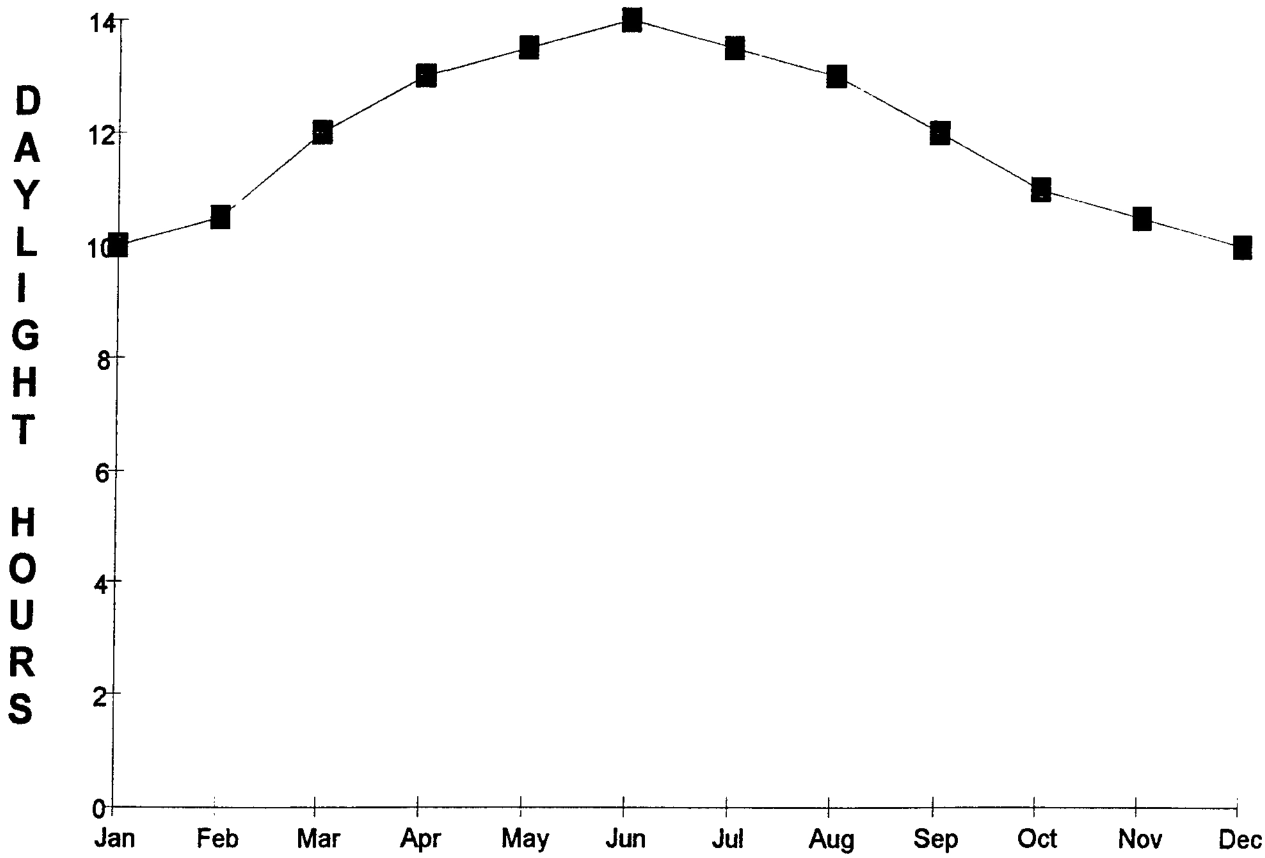

Fig. 5. Photoperiod for Macon, Georgia

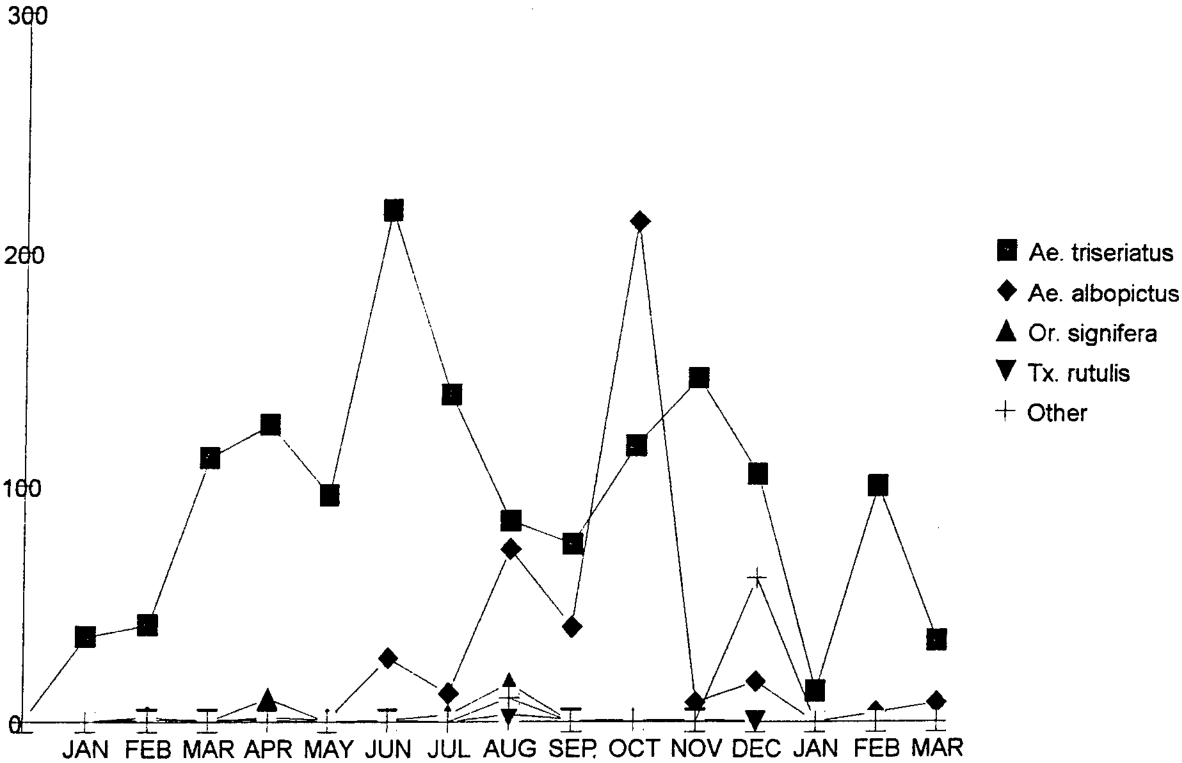

Fig. 6. Monthly Collections, 1993-1994

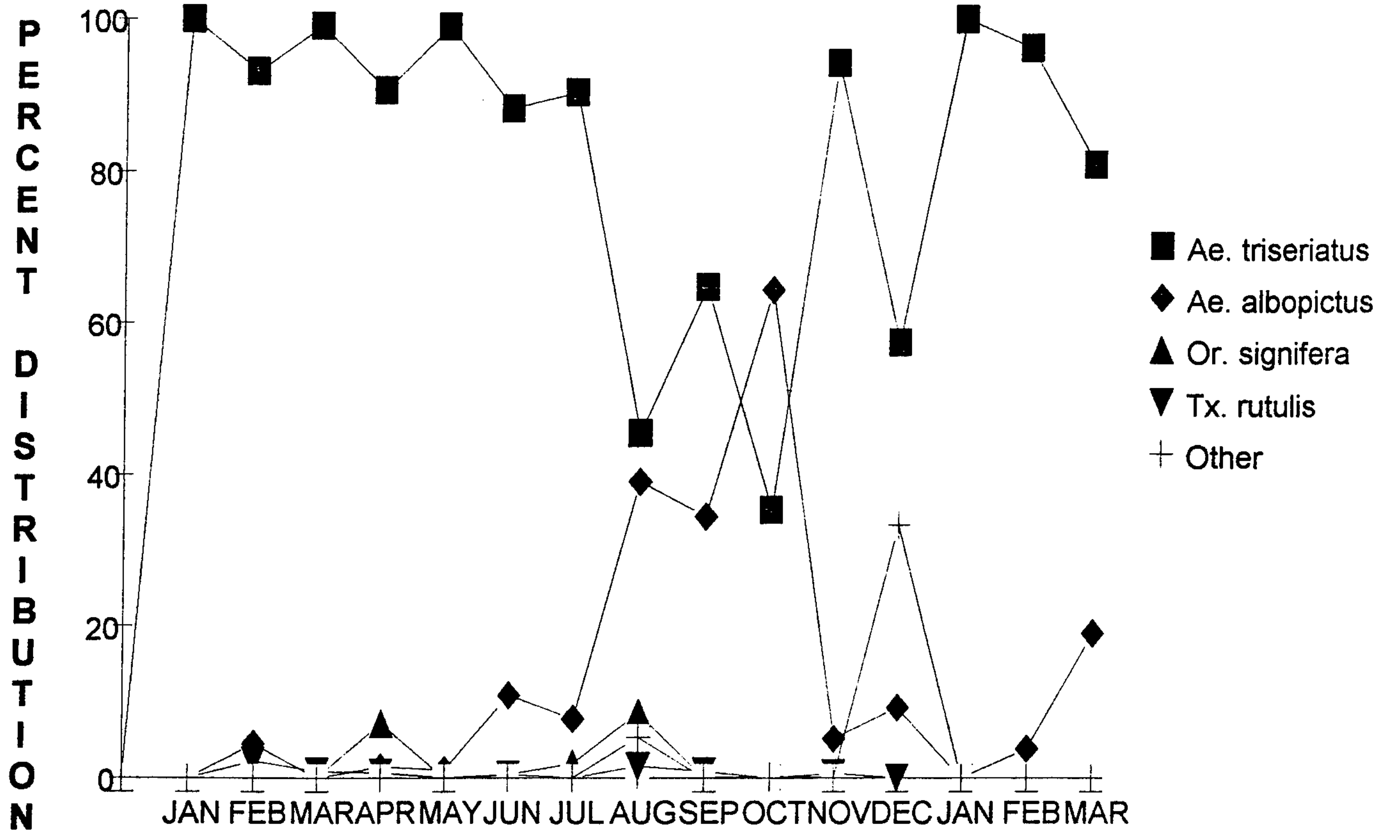

Fig. 7. Monthly Prevalence of Larvae, All 31 Sites

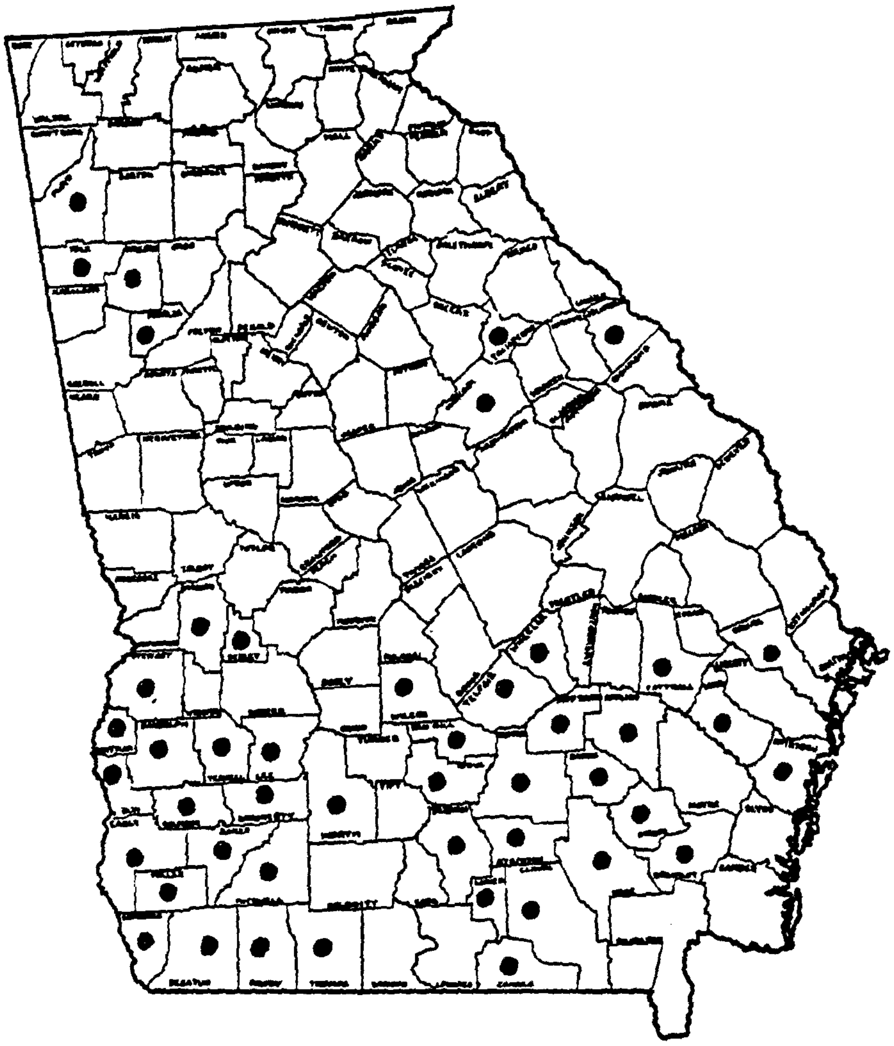

Fig. 8. Counties Added In 1993 By This Project

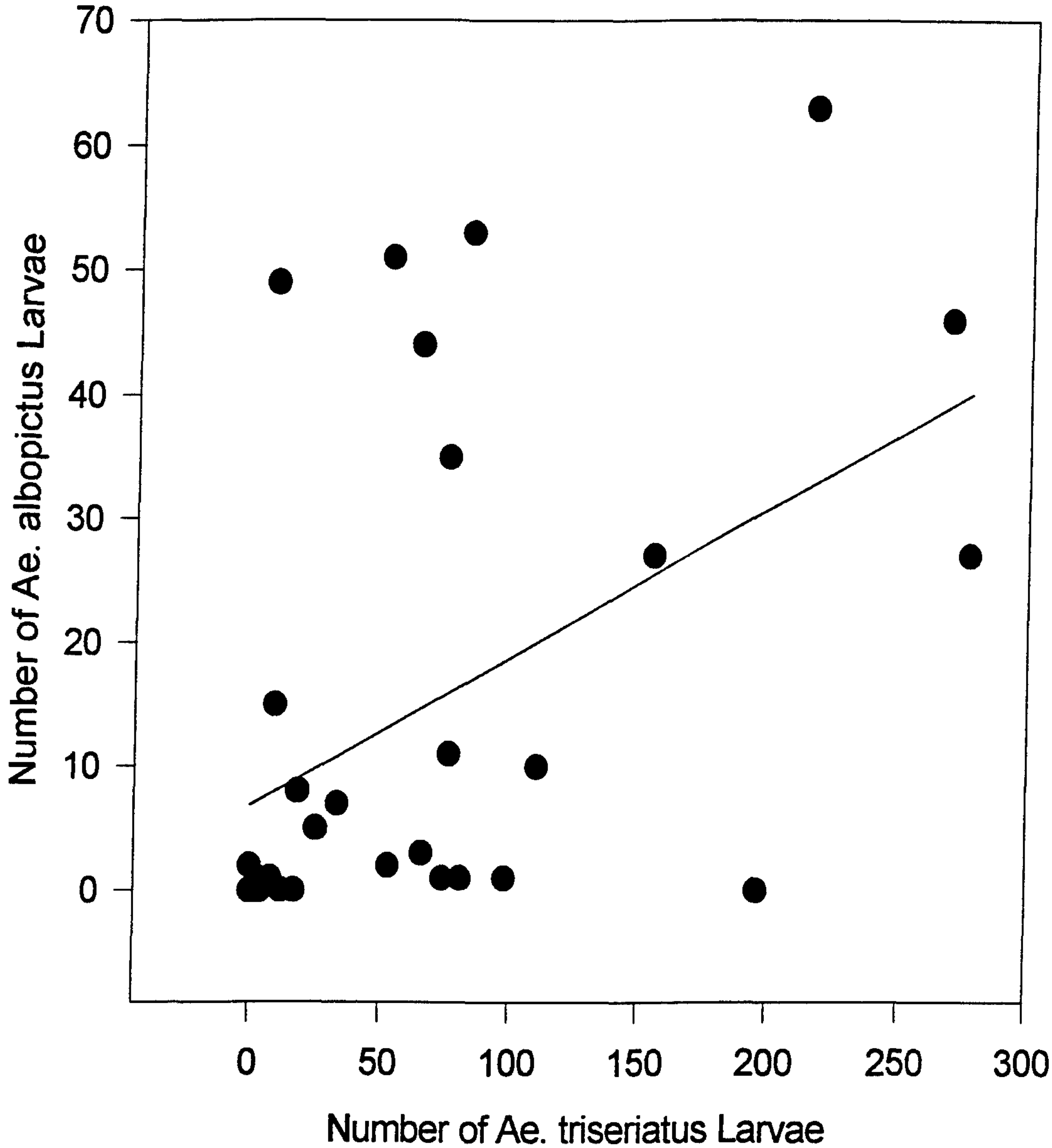

Fig. 9. Correlation of Ae. triseriatus to Ae.albopictus, all sites

Table 1. Results of Tree Hole Survey as of March, 1994

Site No.	Height	Tree Type	No. of Samples	Habitat	PerCent <u>Ae</u>. <u>albopictus</u>
21	49 cm	Red Maple	2	A	100.00
20	79 cm	Pecan	3	B	62.50
25	85 cm	Live Oak	3	B	57.64
26	24 cm	Wild Plum	3	A	49.51
3	84 cm	Sweet Gum	3	A	40.74
28	4 cm	Sweet Gum	7	A	38.97
5	75 cm	Red Maple	5	A	31.53
23	13 cm	Winged Elm	3	A	30.76
24	13 cm	Sweet Gum	2	A	25.00
15	9 cm	Sweet Gum	1	A	25.00
2	24 cm	Black Gum	8	A	22.58
44	45 cm	Sweet Gum	5	A	17.50
27	61 cm	Water Oak	3	A	16.66
45	38 cm	Black Gum	6	A	14.83
32	176 cm	Hackberry	5	A	12.64
1	8 cm	Black Gum	11	A	12.47
7	5 cm	White Oak	2	A	11.11
30	133 cm	Sweet Gum	6	A	8.88
31	146 cm	Hackberry	5	A	8.26

A = Suburban   B = Urban   C = Sylvatic

Table 1. (Cont.)

22	114 cm	Hackberry	3	A	4.28
29	4 cm	Willow Oak	3	A	3.57
9	44 cm	Sweet Gum	2	C	1.33
18	68 cm	Sweet Gum	1	A	1.20
33	14 cm	Red Maple	5	A	0.99
10	28 cm	Red Oak	2	C	0.00
13	80 cm	Mulberry	2	A	0.00
4	172 cm	Hackberry	1	A	0.00
6	7 cm	Red Maple	1	A	0.00
8	36 cm	Sweet Gum	1	A	0.00
11	41 cm	Red Oak	1	C	0.00
14	45 cm	Red Maple	1	A	0.00

A = Suburban B = Urban C = Sylvatic

Table 2. New County Records for *Ae. albopictus* in Georgia

County	City	County	City
Appling	Rural	Jeff Davis	Rural
Atkinson	Pearson	Lanier	Stockton
Bacon	Alma	Lee	Leesburg
Baker	Newton	Long	Greenville
Ben Hill	Fitzgerald	McIntosh	Darien
Berien	Ray City	Marion	Buena Vista
Brantley	Nahunta	Miller	Colquitt
Bryan	Richmond Hill	Mitchell	Bacontown
Calhoun	Edison	Paulding	Dallas
Chattahoochee	Cusseta	Pierce	Blackshear
Clay	Ft. Gaines	Quitman	Georgetown
Clinch	Homerville	Randolph	Cuthbert
Coffee	Douglas	Schley	Ellaville
Columbia	Appling	Screven	Wayne
Decatur	Climax	Seminole	Donalsonville
Dodge	Rural	Stewart	Richland
Doughterey	Albany	Taliaferro	Crawfordsville
Douglas	Douglasville	Tarrell	Parrott
Early	Blakely	Tattnall	Rural
Echols	Statenville	Telfair	McRae
Floyd	Rome	Webster	Preston
Grady	Cairo	Wheeler	Alamo
Hancock	Sparta	Wilcox	Abbeville
Irwin	Ocilla	Worth	Warwick

Appendix 1

OVITRAPPING SITES

Georgia

BOLINGBROKE

Site #15	

CENTERVILLE

Site #13	112 Morning Dove Ln.
Site #14	

ELKO

Site #20	
Site #37	741 Highway 26E

FORSYTH

Site #17	Maynard Mill Rd.

FT. VALLEY

Site #5	Rt. 3 Box 860
Site #34	

GRAY

Site #27	Rt. 4 Box 1047

HAWKINSVILLE

Site #36	102 Chris Dr.

LIZELLA

Site #18	

MACON

Site #1	523 Pinecrest Dr.
Site #2	3360 Sandra Faye Dr.
Site #3	2364 Price Dr.
Site #7	Round Table Ln. LWW

Site #8	419 Penn Ave.
Site #9	1151 Ousley Place
Site #11	571 Bel Meade
Site #12	847 N. Confederate Ave.
Site #16	5867 Leone Dr.
Site #21	185 Coventry Cove
Site #23	New Forsyth Rd.
Site #24	929 Underwood Dr.
Site #25	954 North Ave.
Site #28	3997 Emory Dr.
Site #29	9420 Lwr. Thomaston Rd.
Site #30	7171 Hartley Bridge Rd.
Site #32	6055 Thomaston Rd.
Site #35	2545 St. Claire Dr.
Site #38	1237 Timberlane Dr.
Site #39	2543 Delano Dr.
Site #40	187 N. Spring Ct.
Site #43	120 Corbin Ave.
Site #44	4819 Massey Rd.
Site #46	1080 Toombs St.
Site #48	1765 Rivoli Ln.
Site #49	562 Pierce Dr. W.

MUSELLA

Site #33

PERRY

Site #6

WARNER ROBINS

Site #4	
Site #10	Gilcrest Dr.

Site #22	121 Margaret Dr.
Site #26	201 Grove Ln.
Site #31	36 Green St. Lot 84
Site #41	407 Alabama Ave.
Site #45	P.O. Box 1701 104 Whitley Dr.
Site #47	241 Fairways Dr.

A PSYCHOMETRIC EXAMINATION OF 16 MEASURES OF COGNITIVE INFORMATION PROCESSING

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Abstract

An individual differences examination of 16 measures of cognitive information processing was carried out. The measurement quality and validity of both reaction latency and number correct scores were investigated. Relations between reaction latency and number correct scores and various traditional criteria were investigated. Reasonable overlap between the tests constructed from the traditional cognitive perspective and the various intellectual criteria was seen. This was especially true for the composites constructed from the number correct scores. A general description of the focus for the remaining analyses to be carried out is also given.

A PSYCHOMETRIC EXAMINATION OF 16 MEASURES OF COGNITIVE INFORMATION PROCESSING

Mary A. Roznowski

Introduction

This report describes the initial analyses carried out in a study of the measurement quality and construct validity of a battery of cognitive information processing measures. The tests are part of a batter of measures called the APT (Automated Personnel Testing). Additional analyses are being carried out to investigate identifiable characteristics of test items---item "facets"---and their impact on psychometric properties of items and tests. This continuing series of studies will investigate whether such facets can be reliably identified. Further, how these facets impact on item quality and item and test psychometric properties will be investigated.

It should be pointed out that these results reflect very preliminary analyses. Unfortunately, the data were not available and usable for analyses until eight months into the start of this project which was January, 1993.

A description of the different tests to be analyzed is given first. Sixteen tests were included in the battery. Along with the name of the test is an acronym to be used in various tables.

Cognitive Test Battery

Skill learning---SLQ3: Subjects memorize a list/set of rules which they will need to know in order to perform the test. Subjects are presented a number and then are required to identify whether it is a positive or negative number in order to determine which set of rules is to be applied.

Inductive reasoning spatial---INS2: Subjects are given a series of three figures, and they are asked to determine the next figure in the sequence.

Inductive reasoning quantitative---INQ3: This test uses a 9-cell number matrix that has one cell empty. Subjects must figure out the rule that is being followed in the number series and determine the correct number for the missing cell.

Fact learning spatial---FLS1: Subjects are to remember two figures which are presented separately on their own 9-point grids. The test will present one figure from the pair and subject has to recall the second figure.

Working memory spatial---WMS3: Subjects are to perform an arithmetic operation on two matrices containing an arrangement of lines. The subject responds by drawing the answer to the problem.

Working memory quantitative---WMQ4: Subjects must remember the last three numbers of a string of 3 to 6 digits. If the number is in white, then the subject recalls that number. If it is in red, then they must subtract that number from 10 and remember the new number. Subjects' response consists of typing in the last three numbers of the sequence in the correct order.

Working memory verbal---WMV1: The subject is given a set of three rules governing the ordering of a set of objects. The subject has to determine the correct ordering of the four elements of the set.

Skill learning verbal---SLV2: One of two rules is applied to an item. An item consists of two words representing 1 or 2 time periods. If both words refer to the same time

period, then the subject picks the option which is from the same period. Otherwise, if the two words represent different time periods, the subject responds with the remaining time period (future, if cues were today and yesterday, for example).

Processing speed spatial---PSS1: The subject has to transform the given red and blue rectangles to a new configuration either by moving a square vertically in front of or in back of another square or by moving a rectangle horizontally in front of or in back of another rectangle.

Processing speed quantitative---PSQ2: The subject is given 6 seconds to determine if the arithmetic problem is correct. Half of the answers are true, and the other half are false.

Processing speed verbal---PSV4: The subject determines whether two words are the same or different.

Fact learning verbal---FLV3: Subjects memorize a long list of words which are presented simultaneously. Subjects then determine whether or not the presented word was part of the list.

Fact learning quantitative---FLQ2: Subjects attempt to memorize a large set of numbers which are presented simultaneously. Subjects then determine whether or not a presented number was a part of the learned list.

Inductive reasoning verbal---INV1: Three word sets of three words, names or phrases are presented simultaneously to subjects. The subject is required to determine which of the three sets does not correspond or fit with the remaining sets.

General knowledge quantitative---GKQ0: Questions about general factual information with quantitative or numerical subject matter are asked of subjects.

General knowledge spatial---GKS2: Questions about general factual information regarding spatial subject matter are asked of subjects.

Sample

The sample consisted of Air Force basic trainees attending Basic Military Training. They were tested on the 11th day of training with training lasting 30 days. Subjects were tested in groups of 40, usually in same sex groups. Subjects were tested on Unisys 386 25mhz microcomputers with 16" multisync non-interlaced color monitors. Testing lasted approximately four hours with a 5-minute break half way through the session. Experimental testing is considered a part of basic training and all recruits are tested on the 11th day. Subjects were able to decline participation in the test session.

The sample consisted of 1,069 males (89%) and 138 females. Also, 98% of the examinees were white, 12% were black and the remaining examinees were of other races. Finally, 99% of the sample had a high school diploma or the equivalent.

Analyses

Preliminary analyses carried out on the data will be presented and described here. Basic psychometric and correlational analyses were carried out on the 16 tests. Various criterion variables were also available along with the cognitive information processing test data. These included scores from eleven tests from the Armed Services Vocational Aptitude Battery (the ASVAB). Scores of four subscales

were also available for each examinee as were AFQT scores. Two types of scores were used for the analyses reported here. Latencies were used which reflect the time to respond from the presentation of the stimulus. Also, a score indicating correct or incorrect response for each trial was recorded and used. Next, composites were formed for both correlation latencies and number correct scores. These composites were simple unit-weighted composites. Coefficient alpha was investigated for both reaction latencies and number correct scores.

Results

Table 1 contains simple statistics for the 16 unit-weighted reaction time composites. Means, standard deviations, number of examinees and number of trials (items) in the composites are given.

Correlations among reaction time composites are presented in Table 2. The correlations reveal low to moderate, and consistently positive correlations among the various tasks. Thus, there is some degree of general response commonality among these very diverse measures. The average intercorrelation among reaction time composites was .270 (sd = .096).

Simple statistics for number correct composites are given in Table 3. These scores represent unit-weighted composites made up of the binary scores for each trial (0 = incorrect, 1 = correct) summed across trials within a particular test. Means, standard deviations, number of examinees and number of trials (items) in the composites are given.

Correlations among number correct composites are presented in Table 4. Again, the correlation reveals low to moderate, and mostly positive correlations among the various tasks. There again appears to be some degree of general response commonality among these measures. The average intercorrelation among number correct composites was .240 (sd = .112). This average intercorrelation is somewhat

lower than that for the reaction time measures. This result---which reflects a number of near zero correlations in the matrix---may be a result of some badly skewed distributions for some of the number correct composites (such as general knowledge). These results will be explored further in later analyses.

Coefficient alphas are shown in Table 5. Coefficient alphas are presented for both the reaction latency scores and number correct scores. Coefficient alphas for reaction times are consistently high, most being in the .90s. Coefficient alphas for the number correct scores are also consistently high. These results are very encouraging from a psychometric perspective.

Correlations between the two unit-weighted composites (reaction time and number correct) and the criterion variables are shown in Table 6. These validity coefficients are mostly significant, with the exception of correlations for three ASVAB measures and the reaction time composite. On average, the correlations between ASVAB measures and the number correct composite were larger than those for the reaction latency composite. The correlation between AFQT and number correct was sizeable (r = .528).

Discussion/Future Work

Of considerable interest for further work will be the question surrounding which content characteristics contribute to difficulty and item discrimination power. An attempt to identify characteristics related to difficulty will be carried out. Further analyses will examine the content characteristics of items from various tests in this battery that appear to contribute significantly to difficulty and to discriminating power. The ultimate goal here is that content specifications could be refined with a view toward maximizing the yield of items with desired measurement characteristics. Thus, the next goal of this project is to identify content characteristics that would possibly influence responses. Can these characteristics be reliably identified?

Table 1

Simple Statistics for Reaction Time Composites

Variable	N	Mean	Std Dev	n of trials
PSV4	1044	47383	12354	64
PSQ2	1078	92263	20966	30
PSS1	1107	76707	23235	24
WMV1	1172	99693	36317	24
WMQ4	1201	146654	51829	32
WMS3	1207	144237	45965	27
FLV3	1207	378051	71787	192
FLQ2	1207	78023	22096	52
FLS1	1207	287080	70853	24
SLV2	1206	265482	86631	72
SLQ3	1200	272807	93159	192
INV1	1187	205817	56075	20
INS2	1175	193878	50149	20
INQ4	1174	190707	60605	20
GKQ0	1140	213156	54454	28
GKS2	1086	107497	32856	40

Table 2

Correlations among Reaction Time Composites

	PSV4	PSQ2	PSS1	WMV1	WMQ4	WMS3	FLV3	FLQ2
PSV4	1.000							
PSQ2	.379	1.000						
PSS1	.337	.334	1.00					
WMV1	.308	.356	.301	1.00				
WMQ4	.279	.294	.221	.425	1.00			
WMS3	.232	.233	.281	.348	.420	1.00		
FLV3	.405	.402	.302	.362	.280	.320	1.00	
FLQ2	.149	.155	.139	.186	.165	.250	.317	1.00
FLS1	.163	.162	.266	.278	.265	.536	.295	.246
SLV2	.150	.290	.310	.337	.390	.356	.390	.313
SLQ3	.186	.207	.166	.162	.118	.159	.285	.344
INV1	.094	.114	.187	.202	.223	.295	.243	.329
INS2	.115	.063	.262	.225	.181	.250	.257	.333
INQ4	.166	.282	.130	.226	.267	.280	.286	.231
GKQ0	.111	.121	.144	.161	.137	.268	.267	.296
GKS2	.138	.201	.176	.217	.211	.235	.299	.363

Note: N = 1,174. $r \geq .059$ is significant at .05.

Table 2 (continued)

Correlations among Reaction Time Composites

	FLS1	SLV2	SLQ3	INV1	INS2	INQ4	GKQ0	GKS2
FLS1	1.00							
SLV2	.341	1.00						
SLQ3	.163	.299	1.00					
INV1	.396	.332	.261	1.00				
INS2	.380	.354	.264	.565	1.00			
INQ4	.279	.278	.224	.343	.345	1.00		
GKQ0	.359	.231	.237	.518	.493	.363	1.00	
GKS2	.242	.321	.243	.335	.395	.302	.407	1.00

Note: N = 1,174. $r \geq .059$ is significant at .05.

Table 3

Simple Statistics for Number Correct Composites

Variable	N	Mean	Std Dev	n of trials
PSV4	1044	56.66	7.95	64
PSQ2	1078	26.57	3.23	30
PSS1	1106	20.28	3.93	24
WMV1	1172	17.18	5.56	24
WMQ4	1207	28.27	5.97	32
WMS3	1207	16.95	6.94	27
FLV3	1207	167.31	15.60	192
FLQ2	1207	40.30	5.47	52
FLS1	1207	10.19	5.42	24
SLV2	1206	62.91	11.69	72
SLQ3	1200	164.69	28.76	192
INV1	1187	12.00	3.67	20
INS2	1175	15.85	2.55	20
INQ3	1174	16.80	3.96	20
GKQ0	1140	9.04	2.83	28
GKS2	1086	33.64	4.84	40

Table 4

Correlations among Number Correct Composites

	PSV4	PSQ2	PSS1	WMV1	WMQ4	WMS3	FLV3	FLQ2
PSV4	1.00							
PSQ2	.161	1.000						
PSS1	.131	.151	1.000					
WMV1	.113	.222	.340	1.000				
WMQ4	.103	.212	.245	.443	1.00			
WMS3	.078	.171	.378	.417	.289	1.00		
FLV3	.173	.227	.296	.369	.274	.410	1.00	
FLQ2	.087	.139	.187	.269	.188	.333	.408	1.00
FLS1	.045	.071	.315	.353	.199	.563	.349	.317
SLV2	.134	.230	.297	.330	.277	.363	.373	.268
SLQ3	.141	.175	.316	.399	.273	.467	.397	.316
INV1	.113	.132	.260	.308	.119	.316	.256	.221
INS2	.094	.102	.307	.305	.179	.443	.317	.252
INQ3	.064	.108	.179	.257	.207	.329	.287	.234
GKQ0	.045	.065	.110	.125	.046	.164	.134	.108
GKS2	-.017	.080	.211	.194	.114	.275	.175	.161

Note: N = 1,174.

Table 4 (continued)

Correlations among Number Correct Composites

	FLS1	SLV2	SLQ3	INV1	INS2	INQ3	GLK0	GKS2
FLS1	1.00							
SLV2	.305	1.00						
SLQ3	.416	.448	1.00					
INV1	.279	.281	.333	1.00				
INS2	.433	.347	.374	.330	1.00			
INQ3	.282	.325	.323	.288	.368	1.00		
GKQ0	.164	.140	.158	.240	.212	.142	1.00	
GKS2	.242	.187	.219	.142	.251	.243	.157	1.00

Note: N = 1,174. $r \geq .059$ is significant at .05.

Table 5

Coefficient Alphas for Composites

Variable	Reaction Time Composites	Number Correct Composites
PSV4	.971	.789
PSQ2	.954	.684
PSS1	.939	.821
WMV1	.935	.863
WMQ4	.930	.872
WMS3	.867	.913
FLV3	.980	.920
FLQ2	.923	.737
FLS1	.856	.864
SLV2	.975	.956
SLQ3	.978	.977
INV1	.890	.697
INS2	.864	.643
INQ3	.848	.863
GKQ0	.912	.295
GKS2	.907	.597

Note: N = 1,174.

Table 6

Correlations between ASVAB tests and Composites

	Reaction Time Composite	Number Correct Composite
General Science	-.099	.287
Arithmetic Reasoning	-.257	.487
Word Knowledge	-.117	.268
Paragraph Comprehension	-.065	.257
Numerical Operations	-.183	.210
Coding Speed	-.192	.218
Auto and Shop Information	-.002	.058
Math Knowledge	-.175	.449
Mechanical Comprehension	-.079	.281
Electronic Information	-.020	.188
Word Knowledge and Paragraph Comprehension	-.115	.304
Mechanical	-.052	.200
Administrative	-.238	.331
General	-.244	.505
Electrical	-.185	.486
AFQT	-.231	.528

Note: N = 1207. All correlations except those indicated are significant at the .05 level.

A SIMPLIFIED MODEL FOR PREDICTING JET IMPINGEMENT HEAT TRANSFER

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Abstract

The effects of high temperature ($\geq 1000^{\circ}$ F) jet blast on runway pavement surfaces has become a major concern, especially now with the increasing prominence of V/STOVL (vertical/short take-off and landing) aircraft. In an attempt to model normal and oblique jet impingement heat transfer, a computer code has been developed based on the Hiemenz solution of the Navier-Stokes equations. The primary use of the code will be to provide values of heat flux and surface temperature, for use as input to finite element solid mechanics modeling codes, to predict and quantify stresses in runway pavement materials due to high heat flux. As a result of this research effort, the initial steady-state version of the code has now been modified in order to predict transient values of surface temperture, and to model stagnation flow over rough surfaces.

A SIMPLIFIED MODEL FOR PREDICTING JET IMPINGEMENT HEAT TRANSFER

Mark E. Kithcart

INTRODUCTION

In recent years, significant effort has been directed towards the problem of concrete runway degradation as a result of periodic, intense, jet blast from military aircraft. With the increasing prominence of V/STOVL (vertical/short take-off and landing) technology, the problems associated with this phenomenon have become more acute.

As with most research-based engineering endeavors, the solution to this problem has been sought using both experimental and analytical approaches. Experiments have focused on testing concrete pavement material (both on-site and in the laboratory) in order to determine the mechanisms of material breakdown as result of thermal input. Full-scale high heat (approximately 1000° F) conditions have been produced using actual military aircraft for experimental purposes.

Analytically, the focus has been on modeling the mechanisms which lead to concrete failure due to thermal stresses, with the more complex models considering the inhomogenous nature of concrete and the resulting differential thermal stresses induced by heat transfer. Finite element codes are widely used in these efforts. In terms of modeling the actual thermal (convective) output of of jet engines and the resultant heat flux and temperature created when directed towards a surface, the few codes in existence (Bose [1], and Abelhoff, *et al* [2], for example) are very complex in nature, and require expensive computer hardware in most cases

to obtain accurate solutions in a short time period.

Due in part to the considerations expressed above, a short, user-friendly jet impingement heat transfer code has been written to predict temperature and heat flux on a solid surface subject to to impinging jet flow. The code is based on the Hiemenz stagnation region solution of the Navier-Stokes equations as presented by White [3]. The governing differential equation is solved in an iterative manner using a fourth-order Runge-Kutta integration algorithm coupled with an iterpolation scheme based on the half interval method. As a result of this research effort, the code in its present form is now capable of modeling transient temperature conditions at the surface, along with oblique impingement, and impingement onto rough surfaces.

FLOW PHYSICS AND CODE DEVELOPMENT

In this section, an attempt will be made to briefly summarize some of the important details of impinging jet flow, and to describe how these aspects are modeled in the computer code, based on a few simplifying assumptions.

To begin, the primary assumptions are these:

- Axisymmetric flow (from the nozzle to the impingement point)
- Impingement flow region comprises $0 \le r/D_N \le 2$, where r is the radial distance from the stagnation point, and D_N is the nozzle diameter
- Flow in the X-Y plane (see Fig. 1) can be modeled with two-dimensional flow correlations
- The flow field is assumed to be steady, while conduction at the surface is time-dependent
- Properties of the fluid and solid are constant
- When flow over a rough surface is modeled, the surface is assumed to be "fully rough" in the hydrodynamic sense, meaning that the size and density of the roughness are sufficient to have an effect on the flow field
- Flows having a nozzle height to diameter ratio between two and four are of primary interest.

From the nozzle exit down to just above the impinged surface, the flow takes the form of a free jet. In real situations, the jet can be considered turbulent once it reaches the surface, though the level of turbulence is a function of nozzle geometry and the exit velocity. In the present code, the free jet is not modeled expicitly; two correlations

which capture the change in velocity and temperature from the nozzle to the surface are used instead. The temperature correlation, developed by Rajaratnam [5] is

$$T_{INF} = T_N \, C \left(\frac{H}{D_N} \right)^{0.5} \tag{1}$$

where C has a value of 0.9, based on numerical experimentation, T_{INF} is the fluid temperature just above the impinged surface, T_N is the fluid temperature at the nozzle exit, H is the nozzle height above the surface, and D_N is the nozzle diameter. The velocity correlation was found experimentally by Dosdogru [6], and is given by

$$A = \left(\frac{V_N}{D_N} \right) \left(1.04 - 0.034 \, H/D_N \right) \tag{2}$$

where V_N is the velocity at the nozzle exit, D_N is the nozzle diameter, and H is the height of the nozzle above the surface. The parameter A is a constant which is used in the stagnation flow region velocity calculations described below.

At the impinged surface, the free jet is transformed into stagnation point flow, shown in Fig. 1. This flow regime is characterized by a zero-velocity stagnation point, which the impinged fluid moves away from in the form of an accelerating boundary layer. The velocity and heat flux conditions in this region are modeled in the code using the Hiemenz solution of the Navier-Stokes equations, as presented by White [3, 7]. The governing differential equation is

$$f''' + 2ff'' + (1 - f'^2) = 0 \tag{3}$$

with boundary conditions

$$f(0) = f'(0) = 0, \; f'(\infty) = 1 \tag{4}$$

where the primes denote differentiation with respect to the dimensionless parameter η, equal to $y*(A/\nu)^{0.5}$, with y as the physical dimension normal

to the surface, A is the velocity parameter calculated in equ. (2), and ν is the kinematic viscosity. The equation which desribes the thermal boundary layer [3, 7]

$$G(\mathrm{Pr}) = \left[\int_0^\infty d\eta \, \exp(-2\mathrm{Pr}\int_0^\eta f \, ds) \right]^{-1} \qquad (5)$$

is solved simultaneously with equs. (3) and (4), using a 4th-order Runge-Kutta algorithm [3], coupled with an interpolation scheme based on the half-interval method. In equ. (5), Pr is the Prandtl number, and f is a solution of equ. (3). The instantaneous heat flux in the stagnation flow region is calculated subsequently using

$$q_w = k(T_\infty - T_w) \, G(\mathrm{Pr}) \, (A/\nu)^{0.5} \qquad (6)$$

where k is the fluid thermal conductivity, T_∞ is the fluid temperature just above the surface, and T_w is the surface temperature of the solid.

As mentioned previously, the impinged fluid accelerates away from the stagnation point in a boundary layer-type flow regime. Though equ. (3) accounts for the overall heat flux in the stagnation flow region, there are still convective effects at the surface which should be recognized. Here, the experimental results of Hoogendoorn [8] and Cooper *et al* [9] provide a great deal of insight into the nature of the flow field. Both data sets indicate that the fluid accelerates outward to approximately $r/D_N = 1$ (Hoogendoorn's Fig. 7 indicates about 1.05, Cooper *et als*' Fig. 6 indicates 1). To model the convective heat transfer, the Nusselt number relation presented by White [7] is used

$$\mathrm{Nu}_r = \frac{q_w \, r}{k(T_\infty - T_w)} = G(\mathrm{Pr}) \, \mathrm{Re}_r^{0.5} \qquad (7)$$

where q_w is calculated in equ. (3), k is the fluid thermal conductivity, T_∞ and T_w are the respective fluid and surface temperatures, and r is the

radial distance from the stagnation point. The parameter G(Pr) is obtained from equ. (5), and Re_r is a Reynold's number equal to Ar^2/ν, where A is the velocity parameter from equ. (2). Equ. (7) indicates that the Nusselt number (and consequently, the heat transfer coefficient) varies as a function of velocity and radial distance in the accelerating flow region, a subject which is discussed in more detail later.

After the passing through the point of maximum velocity, the impinging fluid begins to deccelerate (see the figures cited above) and starts a transition to turbulent wall jet flow. In order to account for the decceleration of the flow field, an empirical equation derived by Hrycak [10] from experiments which studied impinging jet boundary layer flow is used

$$v_m = 0.6\ A\left(\frac{r}{D_N}\right)^{-1.12} \tag{8}$$

where v_m is the maximum velocity in the boundary layer, r is the radial distance from the stagnation point, D_N is the nozzle diameter, and A is the velocity parameter from equ. (2). The constant 0.6 is used instead of the value of 1.4 given in [10], in order to scale the equation with the parameter A rather than the nozzle exit velocity used in [10].

From the transition point out to the edge of the computational domain at $r/D_N = 2$, the standard turbulent Nusselt number correlation

$$Nu = 0.0296\ Pr^{0.33}\ Re^{0.8} \tag{9}$$

is used to model the turbulent wall jet flow.

Outside of the accelerating flow region, the freestream temperature of the fluid begins to change (Knott [20] indicates that the total temperature in the region $0 \le r/D_N \le 1$ is constant). To model the variation in temperature with radial distance, the relation developed by

Hollworth and Wilson [11]

$$\frac{T_{aw} - T_a}{T_N - T_a} = 1.24(r/D_N)^{-0.1} \tag{10}$$

derived from their experiment which dealt with impinging jet flow, is used. Though this a correlation obtained from data for nozzle diameter to height ratios of five and greater, it can be assumed that it will provide reasonable order-of-magnitude accuracy. In equ. (10), T_N is the fluid temperature at the nozzle exit, and T_a is the ambient air temperature.

In attempting to model oblique jet impingement with the present code, two major obstacles are encountered: One, there is no definitive data set which clearly indicates the effect of impingement angle on heat transfer (for example, Martin [4] reports no significant effect; Sparrow and Lovett [13] show a variation of about 10 - 20%, even down to an angle of 30°, and Goldstein and Fratchett [14] report an fairly wide variation, depending on nozzle height, nozzle Reynold's number, and impingement angle). Two, there exists no detailed study of the stagnation region flow similar in nature to the work of Hoogendoorn or Cooper *et al* cited previously (known to the author). Despite these limitations, there are assumptions which can be made that would allow at the least an order-of-magnitude analysis. First, for the high speed, high temperature flows which are the focus of this effort, a change in impingement angle should not result in a large decrease in heat flux, assuming a constant nozzle to height ratio (no more than 1% per 10° change in angle). Secondly, it can be inferred from Fig. 6 of [14] that an increase of momentum occurs in the flow field downstream of the stagnation point with a decrease in impingement angle. This is most likely due to the increasing prominence

of a horizontal velocity component of the impinging flow. As stated previously, the exact nature of the flow field is not known. However, the assumption can be made that the effect of the horizontal velocity component is to reduce the amount of decceleration in the boundary layer (accounted for in equ. (12)) as the impingement angle is decreased. This could explain the changes seen in Fig. (6) of [14]. Therefore, to model this phenomenon, the exponent of equ. (8), which controls the magnitude of the decceleration, will be incremented by an additive factor of 0.1 for every 10° change in impingement angle. This has the effect of moving the value of the exponent towards zero, and thus the freestream velocity tends towards a constant value.

To account for the effects of surface roughness, the friction coefficient equation for fully rough flow derived by Mills and Hang [15],

$$c_f = \left(3.476 + 0.707\log(r/k) \right)^{-2.46} \tag{11}$$

is used as input for the Reynold's analogy-based rough surface heat transfer equation of Seidman [16]

$$St = \frac{c_f}{2}\left[1 + 0.52\left(\frac{c_f}{2}\right)^{0.725} \left(\frac{U\,k}{\nu}\right)^{0.45} Pr^{0.8} \right]^{-1} \tag{12}$$

where k in both equations is the assumed roughness height, r in equ. (11) is the radial distance from the stagnation point, and U is equal to A times r, where A the velocity parameter from equ. (2). Although equ. (12) agrees well with data from both subsonic and supersonic flow experiments, its performance when modeling pressure gradient flows is unknown. Consequently, this procedure is somewhat *ad hoc* in nature, but it should provide at the very least a "worst case scenario" for heat transfer augmentation due to surface roughness.

Finally, to model the transient conditions at the surface, the

method described by Barakat and Clark [21] was first adopted. This is an explicit, two-dimensional transient algorithm which is claimed to be unconditionally stable. The implementation of this method in the present model has not been tested for all possible configurations and conditions (it would take some time to do so), and there seems to be some unpredictability for convective boundary conditions. Due to this occurence, a one-dimensional explicit conduction method [22] has been inlcuded in the present model. There are of course limitations to this type of method, however, if no modifications are made to the variables in the conduction equation, no problems should result.

Running the code is fairly straightforward, as it is menu driven. Values of velocity and temperature at the nozzle are required, as well as nozzle diameter and height (for oblique impingement, the estimated nozzle center line vertical height is needed, as the code will then calculate the straight line distance to the surface). Options are given for oblique impingement and for impingement onto rough surfaces. All values must be entered in English units (unless one wants to modify the code for other units). The output values of heat flux and heat transfer coefficients are given in SI units, while velocity and temperature are given in English units.

RESULTS AND DISCUSSION

To understand the type of data which can be obtained from the present model, some background should be focused upon. The work of Knott [20] is used as a starting point. This paper is a collection of data and observations relating to Harrier operation and the subsequent ground effects, including damage to runways as a result of jet blast impingement. Examining Fig. 7, Knott indicates that the onset of surface erosion due to Harrier jet blast occurs at approximately $r/D_N = 1$. At this position, there is also a peak in dynamic pressure, which Knott pinpoints as a primary cause of damage (in addition to temperature effects).

Similarly, the results of Baines and Keffer [19] should be mentioned also. Their experiments dealt with measurement of shear stress on a surface created by normal jet impingement. Fig. 6 of their paper shows that the vicinity of $r/D_N = 1$ (x/h in their terminology) is also the location of maximum shear stress (for small nozzle dimension to height ratios). Though the measured shear stress at the stagnation point is not zero, the authors state that this is likely the result of limitations in the experimental equipment.

What is important to note in the two data sets cited is that the parameters measured each displayed peak values in the vicinity of the location where the boundary layer velocity is also a maximum (see again Fig. 6 of [8] and Fig. 7 of [9]). Therefore, when considering the heat transfer parameter (Nu) it would be natural to expect that this would exhibit the same tendencies as the other parameters, that is to say, a dependence on the accelerating flow field. Inspection of Table 1 shows

this to be the case (see also Fig. 4 of Abelhoff *et al* [2]). As a consequence, it is not unreasonable to suspect that the heat transfer coefficient plays a role in creating the conditions necessary for damage to occur as a result of jet blast impingement.

SUMMARY

In an attempt to model normal and oblique jet impingement heat transfer, a computer code has been developed based on the Hiemenz stagnation point flow solution of the Navier-Stokes equations. The primary use of the code will be to provide values of heat flux and surface temperature, for use as input to finite element solid modeling codes, in order to understand stresses in pavement materials due to high heat flux. Preliminary results based on steady-state conditons have shown the code to be in good agreement with experimental and analytical results. The code has now been modified in order to predict transient values of surface temperature, and to model flow over rough surfaces as well.

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STAGNATION FLOW GEOMETRY

Figure 1

Qw(W/SQ M) STAGNATION REGION HEAT FLUX
582518.8

X(FT)	U(FT/S)	NU	H(W/SQ M)
.2	192.178	7610.447	1141.567
.4	384.356	15220.89	1141.567
.6	576.534	22831.34	1141.567
.8	768.712	30441.79	1141.567
1	960.89	38052.23	1141.567
1.2	1021.634	8135.036	203.3759
1.4	859.637	6263.509	134.218
1.6	740.2256	4994.17	93.64068
1.8	648.7438	4089.862	68.16435
2	576.5339	3420.613	51.30919
2.2	518.1614	2910.06	39.68263
2.4	470.0476	2510.802	31.38502
2.6	429.7425	2192.078	25.2932
2.8	395.5136	1933.173	20.71256
3	366.1024	1719.702	17.19701
3.200001	340.5732	1541.404	14.45066
3.400001	318.216	1390.793	12.2717
3.600001	298.483	1262.297	10.51914
3.800001	280.9447	1151.696	9.092333
4	265.2597	1055.74	7.91805

Table 1

GEOSTATISTICAL TECHNIQUES FOR UNDERSTANDING HYDRAULIC CONDUCTIVITY VARIABILITY

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GEOSTATISTICAL TECHNIQUES FOR UNDERSTANDING
HYDRAULIC CONDUCTIVITY VARIABILITY

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Abstract

The spatial variability of hydraulic conductivity is studied using grain-size data collected at a groundwater tracer test site located at Columbus Air Force Base in Mississippi. The study involves vertical kriging, co-kriging and the construction of segmented trend surfaces. It is observed that there exists some simple spatial patterns of hydraulic conductivity. Also, a possible existence of a relationship between the results obtained from grain-size data and the de-trended flowmeter data is shown. In addition, a nonlinear adsorption model, under nonequilibrium conditions, is studied to understand the movement of concentration profiles.

GEOSTATISTICAL TECHNIQUES FOR UNDERSTANDING HYDRAULIC CONDUCTIVITY VARIABILITY

Valipuram S. Manoranjan

1. INTRODUCTION

It is generally recognized that the heterogeneity of aquifer hydraulic conductivity plays an important role in controlling the dispersion and movement of groundwater solutes (5,15). So, there is a great need to quantify spatial variability of hydraulic conductivity if existing transport models are to be applied to practical problems. However, most of the time a large number of hydraulic conductivity measurements are either not available or are impractical to measure in order to study variation in hydraulic conductivity. In this report we carry out a variability study using geostatistical techniques on data collected at a groundwater tracer test site, located at Columbus Air Force Base in Mississippi. In the recent past, somewhat similar studies have been conducted by other researchers (11,12,13,17). These studies were essentially based on borehole flowmeter measurements of hydraulic conductivity, and no serious attempt was made to carry out a thorough study involving indirect measurements such as soil grain-size analyses. It should be noted that there has been some research involving grain-size analyses (3,10). However, these studies were concerned with formulating simple empirical relationships between hydraulic conductivity and median particle size at sand-reservoir bodies and at (apparent) homogeneous sites. We believe that ours is the first serious investigation which uses hydraulic conductivity estimates obtained from grain-size analyses to understand spatial variation in hydraulic conductivity at a heterogeneous site. We base our analysis on new data from the Columbus site which composes a data set more comparable to what would be collected at a "normal" hazardous waste site. Although our analysis is based on the Mississippi AFB test site data, it should be noted that the geostatistical ideas and techniques we develop could be applicable, in general, to any site of interest.

The standard method of approaching a problem of the kind studied here is to introduce the concept of a regionalized variable, (ln[hydraulic conductivity] in this case), and to do kriging, a local estimation technique, which provides the best linear, unbiased estimator, on the regionalized variable over the site (a three dimensional domain). We feel, that such

a three dimensional kriging study might overlook simple patterns the regionalized variable might have in one particular dimension. Therefore, we take a fresh look at this approach and introduce segmentation in the data. Using kriging, but in one direction only, and employing the concept of trend surfaces, we show that spatial variation in hydraulic conductivity can be better understood even with a typical limited data set. Further, we carry out co-kriging analyses in the vertical direction and on horizontal benches.

As pointed out earlier, quantification of spatial variability of hydraulic conductivity is essential to employ transport models for practical problems. However, one should not naively think that once spatial variation pattern of hydraulic conductivity is available, applying transport models is an easy task. There are various unanswered questions associated with transport models and the one we are particularly interested in asks, how to describe transport, analytically, with nonlinear and nonequilibrium adsorption. In this work, we have tried to answer this question also. By studying the one dimensional transport in the positive z direction (along the depth), and using an appropriate linear caricature to describe the nonlinear adsorption, we are able to find the closed form solution for the concentration profile of the solute. It does not matter whether the adsorption is Langmuir or Freundlich, the obtained solution can be easily modified to suit our needs. Such a solution will be very useful for predicting the concentration of a solute in any location at any given time without resorting to expensive numercial computations.

2. HYDRAULIC CONDUCTIVITY ESTIMATES

The experimental data for this study are derived from core samples taken from the saturated zone at the Macro-Dispersion Experiment (MADE) test site at Columbus AFB, Mississippi. Six-inch diameter core samples were collected over the entire saturated depth at seventeen irregularly spaced locations through the center of the tracer plume path. Each core was subdivided into either six or twelve intervals for subsequent chemical and physical analyses. The solid materials in each interval were dried and sieved using U.S. Standard sieves to determine particle size distributions. The data used here are new and are different from the data obtained at the MADE site by Rehfeldt et al. (13). An empirical formula which relates hydraulic conductivity to grain size is used to estimate hydraulic conductivity values for these sieved soil samples. We use the following relationship in the form presented in

(14):

$$K = fd^2$$

where, K is the hydraulic conductivity, d, the representative grain diameter and f, a proportionality factor. The factor f is a function of the uniformity coefficient U given as,

$$U = d_{60}/d_{10}$$

where, d_m is the grain diameter such that $m\%$ of the sample by weight is of diameter less than d_m. Following Seiler (14), when $U \geq 5$ the hydraulic conductivity estimates are based on the formulae

$$K = f(U) \;\; d_{10}^2, \quad 5 \leq U \leq 17$$

and

$$K = f(U) \;\; d_{25}^2, \quad U > 17.$$

The values for $f(U)$ can be obtained from either (13) or (14). However, when $U < 5$, we use the formula

$$K = d_{10}^2$$

due to Hazen (8).

3. PUNCTUAL KRIGING OVER DEPTH

In order to analyze the spatial variability of the hydraulic conductivity estimates obtained using the empirical formulae above, we introduce the concept of regionalized variable. A regionalized variable may be thought of as an intermediate variable between a truly random variable and a completely deterministic one. Unlike random variables, a regionalized variable will have continuity from point to point, but usually it will not be possible to know a regionalized variable's value everywhere, as one could for a deterministic variable. Here, the obvious candidate for the regionalized variable is the hydraulic conductivity, K. However, geostatistics requires that the regionalized variable be normally distributed, and our hydraulic conductivity estimates are not normally distributed. Therefore, a better choice for the regionalized variable is $ln(K)$. Usual practice is to assume stationarity of the regionalized variable and to find the best estimator (with minimum variance) of the mean value of the regionalized variable (punctual kriging) over a two or a three dimensional domain. Thus one obtains some variability pattern of the regionalized variable. Some currently available software packages such as GEOPACK and SURFER (7,16) employ this approach too.

However, the problem with this approach is that, even though one will end up with some kind of resulting variability pattern of the regionalized variable after a lot of computations, interpreting this pattern may not be easy. This pattern may not fall into the category of patterns that can be easily described by polynomial functions, sinusoidal functions etc. So, making predictions based on a complex pattern may not provide the best estimate for determining hydraulic conductivity.

We take a completely different approach in analyzing the hydraulic conductivity data. We investigate the existence of any known simple patterns of either K or $ln(K)$ in a given direction. Therefore, to start we will not do any two or three dimensional kriging, but, instead a one dimensional kriging over depth at each corehole. The first step in the kriging process involves calculating the semi-variogram associated with the experimental data. At this point, the basic assumption is that the log hydraulic conductivity field is stationary. The semi-variogram γ describes the expected difference in value between pairs of samples with a given relative orientation. If we denote the regionalized variable $ln(K)$ by R, the formula that is used to calculate the semi-variogram is given by

$$\gamma(h) = \frac{1}{2n} \sum_{i=1}^{n} [R(z_i) - R(z_i + h)]^2$$

where, z_i and $z_i + h$ are two different depths at a distance h apart and n is the number of sample pairs separated by this distance h, known as the lag distance. The graph γ *vs.* h is the semi-variogram. The computed γ values can be fitted by various models and in most studies the use of linear models has been found adequate (2).

In this study, we carried out kriging at three different locations and it turns out that the corresponding semi-variograms have apparent nugget effects (i.e. discontinuities at the origin) when fitted by spherical models. Generally, the nugget effect can be attributed to fluctuations in soil properties that occur over distances much shorter than the sampling interval. If one has the luxury of closely spaced data, it would be possible to determine the nugget variance with better accuracy. A typical semi-variogram is shown in Fig. 1. Once the form of the semi-variogram is determined, the next step is kriging. Kriging provides the estimated value for the regionalized variable R at any depth at a given location. For a detailed account of kriging, the interested reader should consult (9). Also, (4) and (6) are other good references. For the sake of completeness, we will briefly describe the idea of

kriging in a simple fashion. At a given location, let the number of points z_i employed for kriging be m, and $R_i, (i = 1, 2, \cdots, m)$ be the values of some quantity R at these points. Then, the estimate value $\hat{R}_p$ at any point z_p will be given by

$$\hat{R}_p = W_1 R_1 + W_2 R_2 + \cdots + W_m R_m.$$

(i.e. a weighted sum of the values $R_1, R_2, \cdots, R_m$).

The weights W_i's are not known at this stage and they will be evaluated so that the error associated with the estimate is less than that for any other linear sum involving $R_1, R_2, \cdots, R_m$. It is required that this estimate be unbiased. So, we want $\hat{R}_p$ to be the same as the expectation of the regionalized variable R at location z_p. This amounts to the condition that the weights W_i's should sum to 1:

$$\sum_{i=1}^{m} W_i = 1.$$

The estimation variance at z_p can be obtained as,

$$-\sum_{i=1}^{m}\sum_{j=1}^{m} W_i W_j \gamma_{ij} + 2\sum_{j=1}^{m} W_j \gamma_{pj},$$

where, γ_{ij} is the value of the semi-variogram of pairs of points at a lag distance $|z_i - z_j|$ apart. γ_{pj} is defined similarly. For the estimate we obtain to be the best linear unbiased estimate, W_i's should be found by minimizing the estimation variance subject to the constraint $\sum_{i=1}^{m} W_i = 1$.

This will result in finding partial derivatives with respect to W_i's, introducing the Lagrange multiplier λ and finally showing that the minimum variance is obtained when

$$\sum_{j=1}^{m} W_j \gamma_{ij} + \lambda = \gamma_{ip}.$$

The above equation can be written in the matrix form as

$$AU = b,$$

$$\text{where } A = \begin{bmatrix} \gamma_{11} & \gamma_{12} \cdots\cdots \gamma_{1m} & 1 \\ \gamma_{12} & \gamma_{22} \cdots\cdots \gamma_{2m} & 1 \\ \vdots & & \\ \gamma_{1m} & \gamma_{2m} \cdots\cdots \gamma_{mm} & 1 \\ 1 & 1 \cdots\cdots\cdots 1 & 0 \end{bmatrix}, \quad b = \begin{bmatrix} \gamma_{1p} \\ \gamma_{2p} \\ \vdots \\ \gamma_{mp} \\ 1 \end{bmatrix}$$

$$\text{and } U = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_m \\ \lambda \end{bmatrix}.$$

The minimum estimation variance will be given by $b^T U$.

The interesting aspect of kriging is that, if we choose the point z_p to be any one of the known points z_1 to z_m, the estimate we obtain will be exactly the same as the given value. This can be demonstrated rather easily. For example, if $z_p = z_3$, then our system $AU = b$ will become

$$\begin{bmatrix} \gamma_{11} & \gamma_{12} \cdots\cdots \gamma_{1m} & 1 \\ \gamma_{12} & \gamma_{22} \cdots\cdots \gamma_{2m} & 1 \\ \gamma_{13} & \gamma_{23} \cdots\cdots \gamma_{3m} & 1 \\ \vdots & & \\ \gamma_{1m} & \gamma_{2m} \cdots\cdots \gamma_{mm} & 1 \\ 1 & 1 \cdots\cdots\cdots 1 & 0 \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \\ \vdots \\ W_m \\ \lambda \end{bmatrix} = \begin{bmatrix} \gamma_{13} \\ \gamma_{23} \\ \gamma_{33} \\ \vdots \\ \gamma_{m3} \\ 1 \end{bmatrix}$$

or equivalently,

$$\begin{bmatrix} \gamma_{11} & \gamma_{12} \cdots\cdots \gamma_{1m} & 1 \\ \gamma_{12} & \gamma_{22} \cdots\cdots \gamma_{2m} & 1 \\ \gamma_{13} & \gamma_{23} \cdots\cdots \gamma_{3m} & 1 \\ \vdots & & \\ \gamma_{1m} & \gamma_{2m} \cdots\cdots \gamma_{mm} & 1 \\ 1 & 1 \cdots\cdots\cdots 1 & 0 \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ W_3 - 1 \\ W_4 \\ \vdots \\ W_m \\ \lambda \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \vdots \\ \vdots \\ 0 \end{bmatrix}$$

Now, since the matrix A is non-singular and the right hand side vector is the zero vector, the only possible solution is,

$$\begin{bmatrix} W_1 \\ W_2 \\ W_3 - 1 \\ W_4 \\ \vdots \\ W_m \\ \lambda \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \vdots \\ \vdots \\ 0 \end{bmatrix}.$$

$$i.e. \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \\ \vdots \\ W_m \\ \lambda \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \\ \vdots \\ 0 \\ 0 \end{bmatrix}.$$

Substituting these weights into

$$\hat{R}_3 = W_1R_1 + W_2R_2 + W_3R_3 + \cdots + W_mR_m \qquad \text{(remember } p = 3\text{)}$$

we simply get $\hat{R}_3 = R_3$!

At selected locations, we kriged the data at equally spaced depths and some final results are presented in Figs. 2, 3 & 4. It is interesting to note that the qualitative behavior seems to be the same in all these figures, i.e. hydraulic conductivity increases with depth for a while, then sharply decreases and slowly increases again. (Further computations confirmed that all the corehole profiles behaved in the same fashion.) In Fig. 5 we present all three graphs of Figs. 2, 3 & 4 in one frame. Now, comparing the curves corresponding to the locations (2, 16.3) and (7, 14.6), we may conclude that, at least in the neighborhood of the above coreholes, the variation in the hydraulic conductivity becomes smaller as the x ordinate increases for a nearly constant y ordinate value. Use of higher dimensional kriging would tend to obscure these relatively simple behavioral patterns of hydraulic conductivity.

4. TREND SURFACES

The way we have applied kriging gives us only the variability pattern of hydraulic conductivity in the z direction (depth). In order to investigate the spatial pattern in the x, y directions, we divide the tracer test site into three segments. We call these segments nearfield, midfield and farfield depending on how close or how far they are from the point of tracer injection. Since it is not usually possible to assume stationarity or a trend surface of known form over the entire domain, such segmenting is justifiable. Now picking one of the field segments, at a selected depth we can construct a trend surface for hydraulic conductivity based on the sample data collected just in that field segment. In Figs. 6, 7 & 8 we present such typical trend surfaces obtained (using nonlinear regression) for the nearfield, midfield and farfield, respectively. Initially, linear trend surfaces were tried, but the percentages of goodness of fit were poor. However, for second order trend surfaces, in all three segments, the coefficients of determination turn out to be approximately 0.99. Therefore, the second order trend surfaces are the best possible low order trend surfaces for the experimental data. We tried one second order trend surface for the entire site, at a depth of 28.5 feet, and the corresponding value for the coefficient of determination was 0.44. We also tried a third order trend surface and obtained 0.80 for the coefficient of determination. Although 0.80 is a better value than

0.44, it is still less than 0.99 obtained for the segmented trend surfaces. One can always go another order higher and hopefully find a better trend surface for the whole site. However, it is not advisable to go to higher and higher orders, because that will increase the complexity of the problem. Further, when one has only a limited number of data points, fitting higher order trend surfaces may introduce unwanted artifacts. Therefore, it is our contention that segmenting the test site and fitting a trend surface in each of the different segments is the best way to study the $x - y$ spatial variability of hydraulic conductivity. If a practitioner is interested in hydraulic conductivity variation over the entire three dimensional domain, then at every depth a different set of three trend surfaces should be fitted. However, this task can be easily accomplished using software such as *Mathematica*. It should be noted that, in general, the trend surfaces will not be continuous at the inter-segment boundaries. If one prefers it is possible to fit trend surfaces at constant elevations too.

Our approach kriges in the z-direction and constructs second order trend surfaces in the $x - y$ plane. This gives nice second order polynomial patterns of hydraulic conductivity in the $x - y$ plane, and a simple variation of K in the z direction. Based on a limited sampling study, our approach seems a simple and reasonable way of characterizing the spatial variation of hydraulic conductivity. However, one should remember that kriging is a local estimation procedure, and the kriged estimates are valid only in the neighborhood of the data points considered. Similarly, the trend surfaces cannot be extended to regions far away from the points employed in these surface constructions.

In a recent paper, Rehfeldt et al. (12) studied hydraulic conductivity variability using both borehole flowmeter data and grain-size data. Their estimates of *ln* hydraulic conductivity variance and the horizontal and vertical correlation scales for the site, based on grain-size data, did not fall within the confidence limits of the estimates based on borehole flowmeter data. They reported a borehole flowmeter data variance of 4.5 for *ln* hydraulic conductivity, a 12m horizontal correlation scale, and a 1.5m vertical correlation scale. These same values based on grain-size data are 2.9, 15m and 0.8m respectively. These estimates assumed a second order stationarity of the conductivity field. But, later in the same paper, Rehfeldt et al. (12) argue that trends in hydraulic conductivity should be included because of the large scale spatial variations in the mean groundwater velocity at the site. This argument invalidates the earlier stationarity assumption for the conductivity field. Analyzing further,

the authors assume stationarity of the log conductivity residue field and introduce a third order polynomial trend to represent the conductivity drift based on its compatibility with groundwater flow field. Under these circumstances, working with borehole flowmeter data, the values they obtain for variance and the horizontal and vertical correlation scales (for *ln* conductivity residuals) are respectively 2.8, 5.3m and 0.7m. The values 2.8 and 0.7m for variance and vertical correlation scale are almost the same values they obtained using grain-size data, i.e. 2.9 and 0.8m. This finding suggests that an interesting relationship exists between the results obtained from grain-size data and the de-trended flowmeter data. Further study is needed to clarify this point, but this simple argument shows that grain-size data can be useful in studying hydraulic conductivity variability.

The second point we would like to make is that, although our work has employed only the grain-size data, the approach we have taken (segmented trend surfaces in the $x - y$ plane and vertical kriging) is equally applicable to any other hydraulic conductivity data that can be generated using either direct or indirect methods.

5. CO-KRIGING/GRAIN-SIZE DISTRIBUTION

In theory, one can obtain more accurate results with more data, (i.e. with a larger m value in the equation in Section 3). However, if m is small, and it is felt that the grain-size data is not sampled enough, then it is possible to combine the grain-size data with some other sampled quantity and perform kriging. Such a kriging process is known as co-kriging, and we carried out such an analysis using total organic carbon content (*toc*) data as the other sampled quantity. In this case, one has to keep track of two regionalized variables, *ln* (hydraulic conductivity) and *ln*(*toc*).

In order to perform co-kriging, instead of a semi-variogram one would have a cross-variogram. Generally, the cross-variogram can be written as a linear combination model of the form,

$$\gamma_{12} = \alpha_1 \text{ (function 1) } + \alpha_2 \text{ (function 2)},$$

where function 1 and function 2 are independent functions with α_1 and α_2 being scalar parameters. The functions 1 & 2 are chosen such that for particular choices of α_1 and α_2 the combination model should give the individual semi-variograms corresponding to *ln* (hydraulic conductivity) and *ln* (*toc*). Now, we will also have an additional set of weight-

s $\tilde{W}_i$'s$(i = 1, \cdots, m)$ corresponiding to the regionalized variable $ln(toc)$. Whereas, W_i's corresponding to ln (hydraulic conductivity) satisfy the condition,

$$\sum_{i=1}^{m} W_i = 1$$

$\tilde{W}_i$'s will satisfy the condition

$$\sum_{i=1}^{m} \tilde{W}_i = 0.$$

Initially, we co-kriged the data over depth (in the vertical direction). The corresponding semi-variograms and cross-variogram are presented in Fig. 9. The co-kriged estimates for hydraulic conductivity over depth is given pictorially in Fig. 10. When these co-kriged estimates were compared with direct estimates for hydraulic conductivity (i.e. without involving *toc* data), both sets of estimates were found to be almost the same. This means that either *toc* data has no great influence on hydraulic conductivity variability or grain-size data sampling is good. Although more work is needed to clarify this situation, we tend to think that the former is true. Also, we performed co-kriging on horizontal benches at selected depths and a typical variogram and the spatial variability pattern of hydraulic conductivity are presented in Fig. 11. In order to understand the sensitivitiness of the estimated variability pattern on certain corehole data, we carried out a simple study where certain corehole data were removed from the kriging process. Figs. 12 & 13 give the estimated variability pattern over depth when some corehole data are missing. In the figures, *'Less two'* means two coreholes are missing and *'All'* means all the coreholes are included. As one can see almost all the patterns are qualitatively similar except for the spike value at the depth of 20 feet. The only exception is the pattern at the bottom of Fig. 13. Here, just removing one corehole changed the pattern drastically, implying the influence of that corehole data on the variability pattern. Again, more systematic work is needed to identify the influential coreholes. Such a study can provide important information to do good sampling of data.

In our investigation, we made use of the (widely used) empirical formula (see section 2)

$$K = f(U)d^2$$

which relates the hydraulic conductivity to grain-size distribution. A possible problem with this formula is that it relies only on a *single representative grain diameter*. In our case, that diameter d could be either d_{10} or d_{25} depending on the value of the uniformity constant

U. In a recent article [Alyamani & Sen, (1)] this empirical formula was re-visited and the authors came up with a procedure which relates hydraulic conductivity to the intital slope and intercept of the grain-size distribution curve. We re-visited this empirical formula ourselves, in order to come up with an accurate relationship for hydraulic conductivity (at least for our tracer test site): As an initial exercise when we drew the (corehole) grain-size distribution curves for our (Mississippi AFB) data in a single frame (Fig. 14), an interesting observation was made. All the curves were seen to intersect each other in the small neighborhood corresponding to the percentage value 10 (*i.e. a representative grain diameter* d_{10}). Does this mean d_{10} is a special grain diameter? We investigated further with the help of *Matlab* and came up with the following formula:

$$K = [7.2/d_{10}^2 + 864.8\exp(d_{10}) - 14.79U^4 d_{10}^2 \exp(4d_{10}) + 0.00292(U^{20})d_{10}^{18}]d_{10}^2.$$

This formula fits the data of Alyamani & Sen (1) with a co-efficient of determination of 0.94. However, further research is needed the establish the validity of this formula.

6. CONCENTRATION PROFILE/NONLINEAR ADSORPTION

This part of our work involves a one dimensional transport model. The investigation was motivated by the need for analytical expressions of solute concentration profiles in order to make long term predictions with minimum computational cost and effort. In the past, various authors [van der Zee, (18) and references therein] have studied transport models with the aim of obtaining analytical expressions for concentration profiles. Their efforts have been only partially successful, because analytical expressions were found possible only under local equilibrium assumption or when there was linear sorption.

In our study, we analyse a solute transport model with nonlinear sorption, when sorption kinetics is described by a first order rate expression. In a non-dimensionalized form, the one dimensional model in the positive z direction (depth) can be described as,

[Rate of change in concentration]=[(Dispersion)/(Peclet number)]-[Convection]
-[(a parameter)*(Rate of change in adsorbed amount)]
with
[Rate of change in adsorbed amount]=[a rate constant]*[Nonlinear sorption - Adsorbed amount].

The nonlinear sorption in the above model can be Langmuir, given as,

$$KQC/(1+KC)$$

or Freundlich of the form,

$$KC^n,$$

where C is the solute concentration, K, the nonlinear adsorption coefficient Q, the Langmuir adsorption maximum and n, Freundlich sorption exponent.

We investigate the possibility of constructing travelling wave solutions for solute concentration C. In order to do that, first, we replace the nonlinear sorption function in the model by a suitable linear caricature which has the same qualitative behavior. In particular, we use the linear caricature of the form,

$$f(C) = \begin{cases} K_1 C, & C \le C^* \\ A + K_2 C, & C \ge C^* \end{cases}$$

with appropriate values for the constants A, K_1 and K_2. It is obvious that when we choose $K_2 = 0$ with suitable values for A & K_1, $f(C)$ will have the Langmuir behavior. The concentration value C^* is chosen based on experimental evidence.

Our study involves introducing the travelling wave coordinate

$$Z = z - vt$$

and solving the resulting third order differential equations in the segments $(-\infty, 0]$ and $[0, \infty)$ respectively. By using the matching conditions at the origin, we are able to obtain the continuous concentration profile we were seeking. For the parameter values of [van der Zee, (18)], the concentration profile is as shown in Fig. 15. The corresponding linear caricature is given in Fig. 16.

It should be noted that one can further improve the choice of the linear caricature. For example, by constructing one with three line segments instead of two. Our mathematical treatment can still be applied in such a situation, but, with some extra amount of work. The mathematical ideas employed in this part of our study will be very useful for long term predictions of solute transport over large distances or times. We should point out that

further studies using experimental data are needed for validation of the results obtained here.

7. CONCLUSIONS

The following conclusions can be made based on the study on hydraulic conductivity variability.

The idea of vertical kriging and segmented trend surfaces can provide a simple and understandable view of hydraulic conductivity variability pattern.

The grain size analysis data should not be discarded as useless in the investigation of hydraulic conductivity variability, since the use of grain-size analysis data in such a variability study can give results which can be related to the results one obtains from the (supposedly more accurate) borehole flowmeter data study.

The preliminary results using co-kriging analysis indicate the non-influence of *toc* data on hydraulic conductivity estimates. It is also seen how a single corehole data can have a major influence on the estimated variability pattern.

In the work on the transport model with nonlinear and nonequilibrium adsorption, a closed form solution is obtained for the concentration wave. An expression of this nature will be very useful for predictive purposes and will help experimenters avoid costly numerical computing associated with nonlinear isotherm problems.

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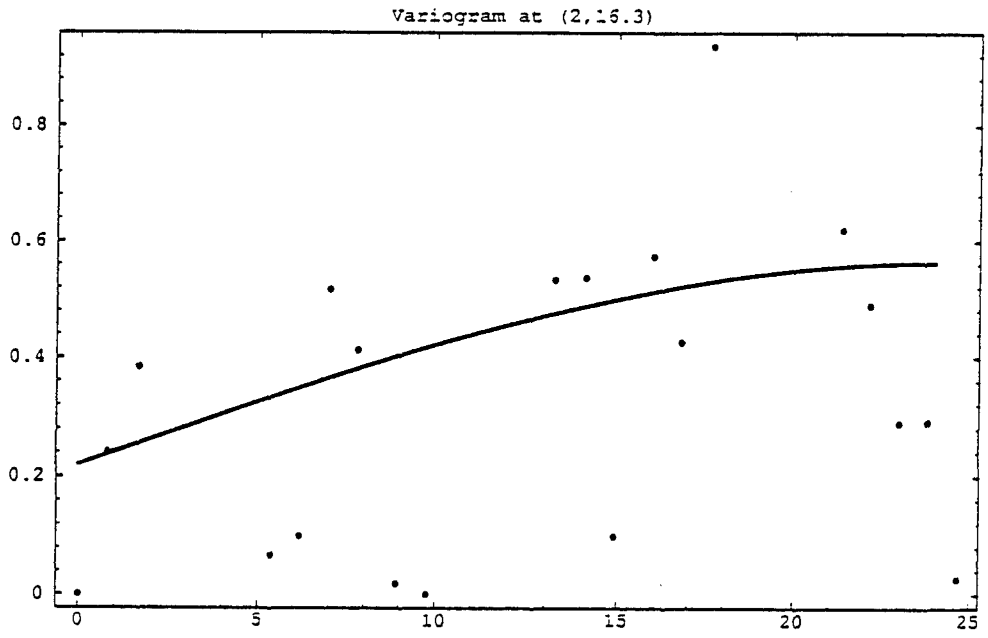


Figure 1

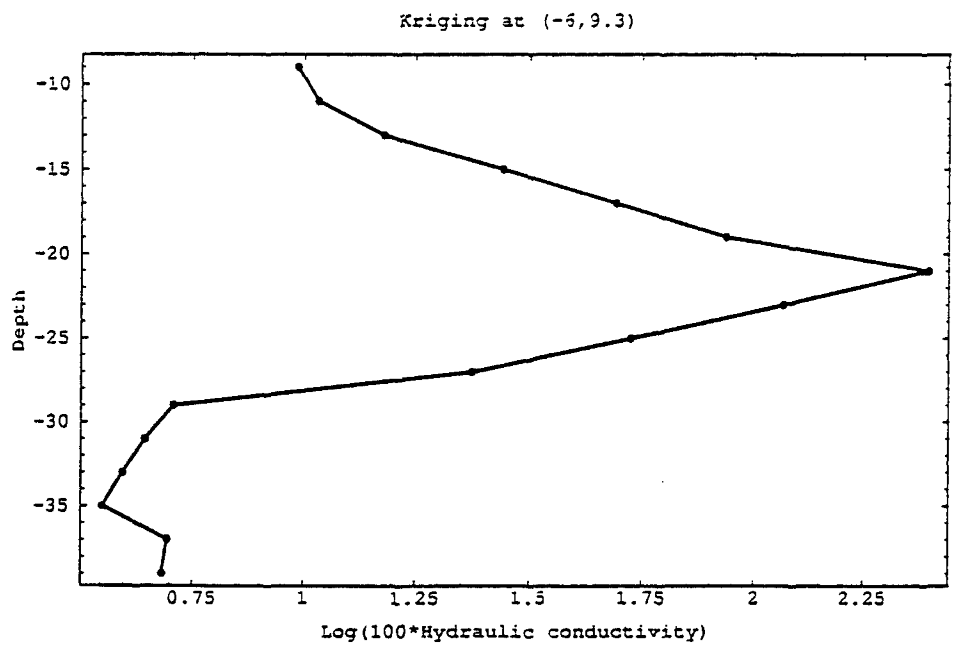
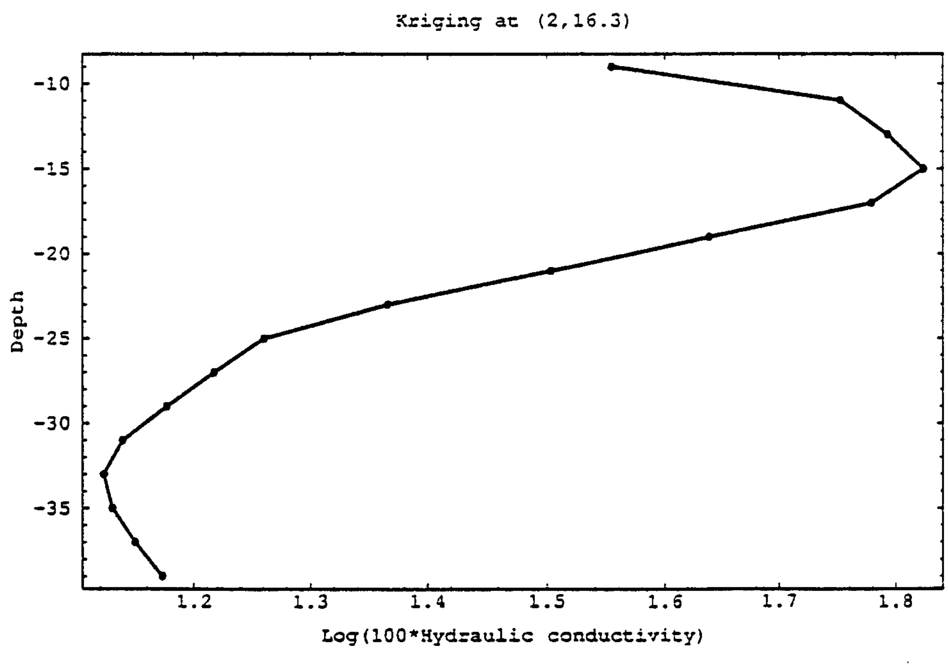


Figure 2



Kriging at (2,16.3)
-10
-15
-20
-25
-30
-35
Depth
1.2
1.3
1.4
1.5
1.6
1.7
1.8
Log(100*Hydraulic conductivity)

Figure 3

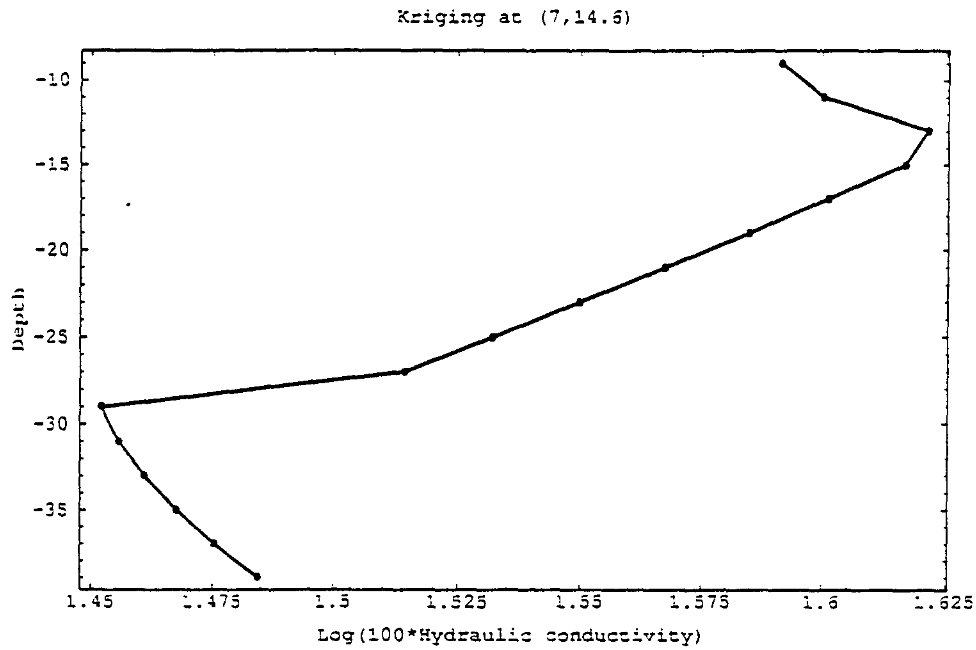


Figure 4

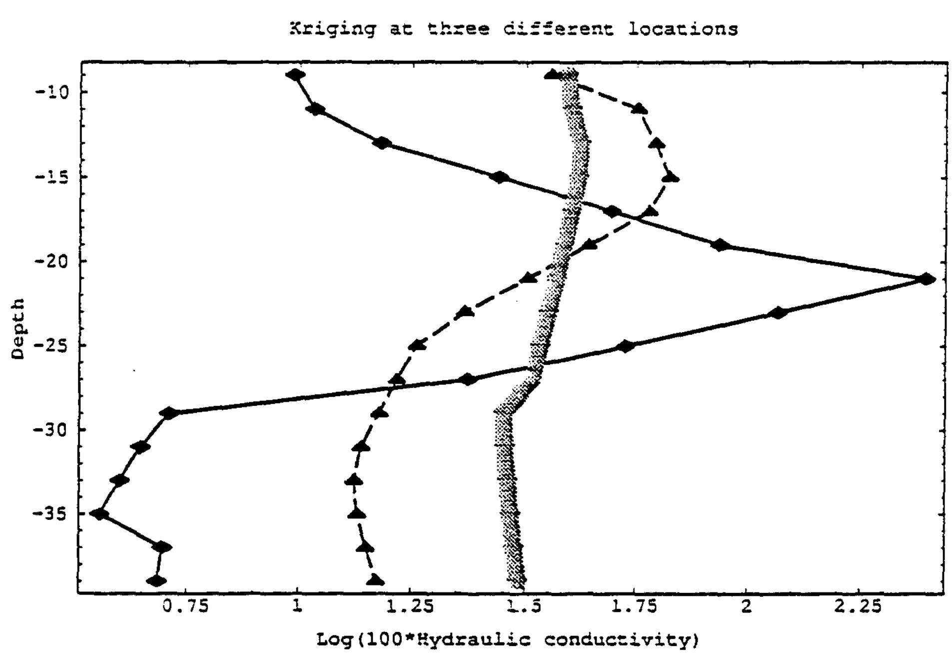


Figure 5

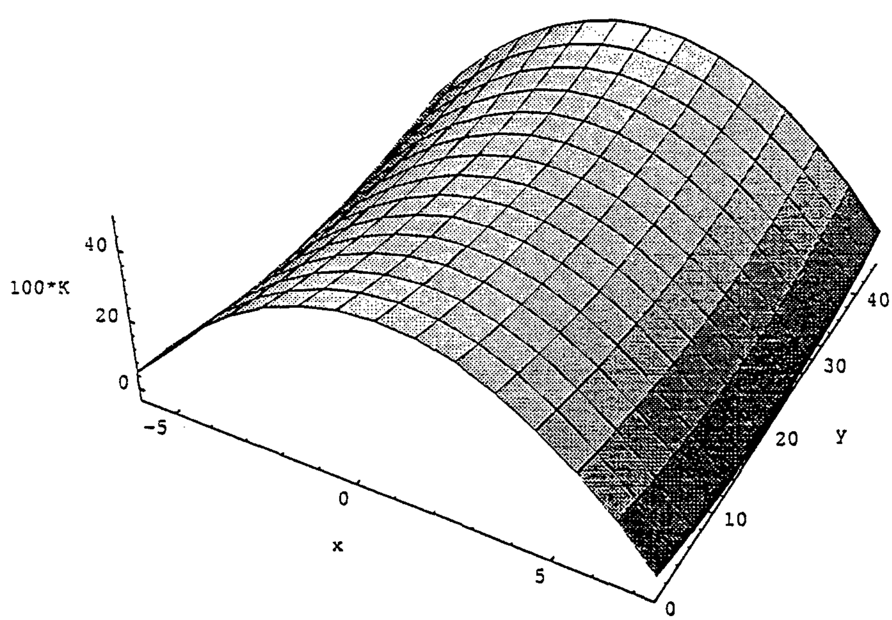


Figure 6
Near Field Trend Surface for Hydraulic Conductivity (Second Order; $R^2 = 0.999$)

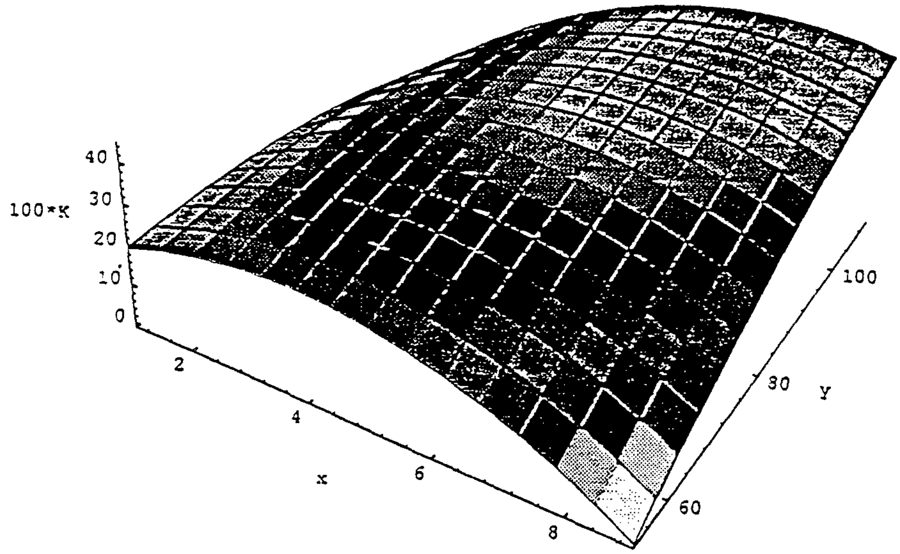


Figure 7
Mid Field Trend Surface for Hydraulic Conductivity (Second Order; $R^2 = 0.999$)

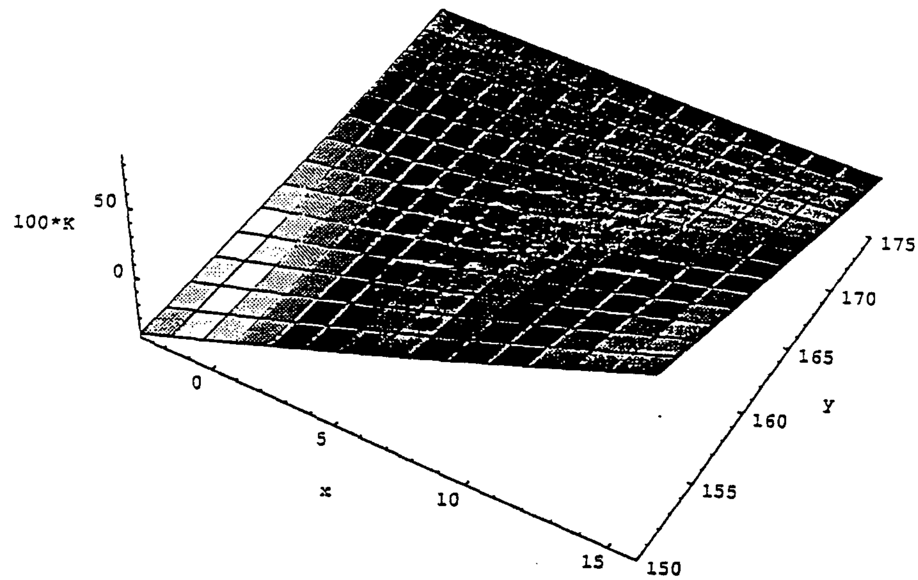


Figure 8
Far Field Trend Surface for Hydraulic Conductivity (Second Order; $R^2 = 0.999$)

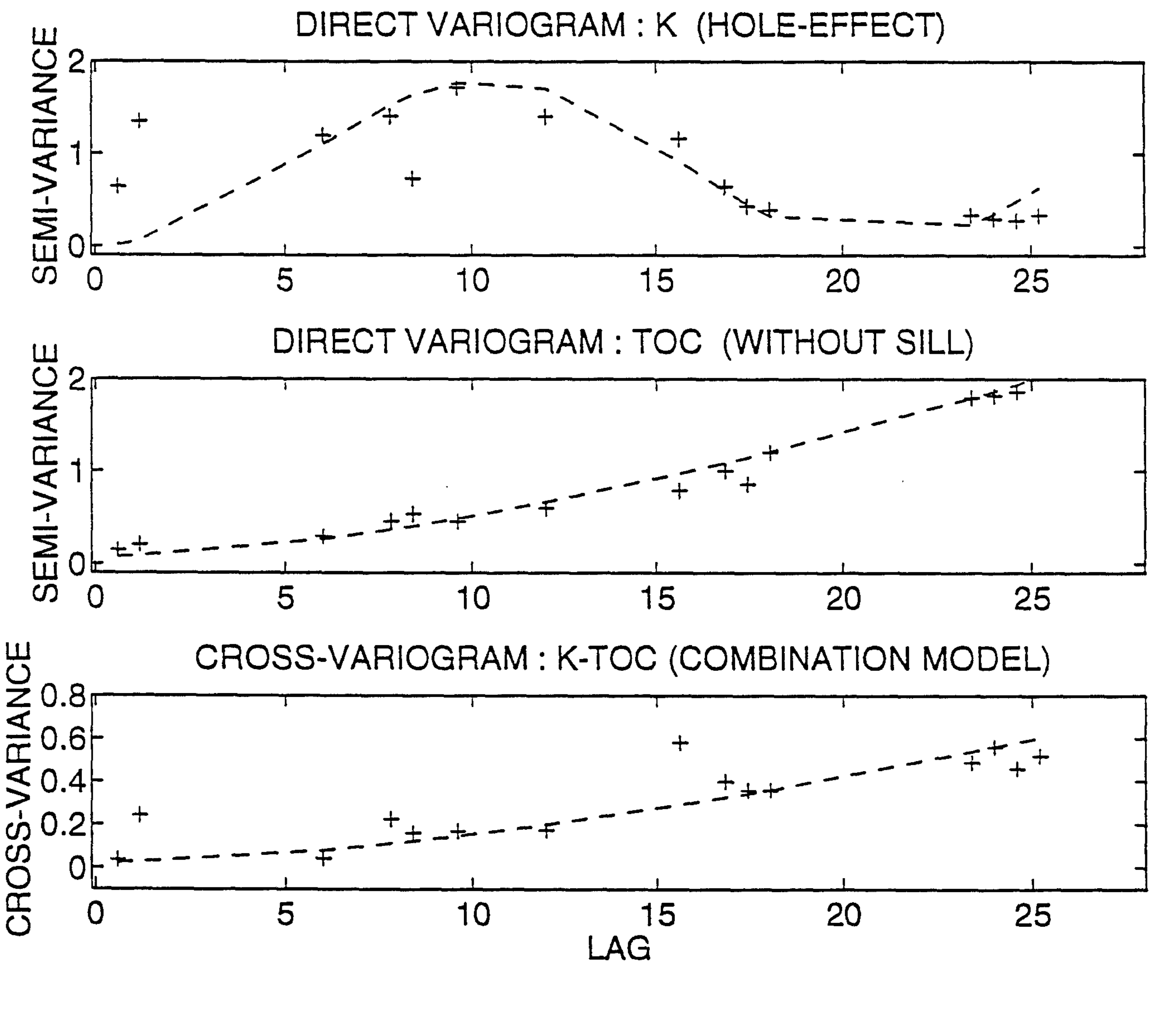

DIRECT VARIOGRAM : K (HOLE-EFFECT)
SEMI-VARIANCE
DIRECT VARIOGRAM : TOC (WITHOUT SILL)
SEMI-VARIANCE
CROSS-VARIOGRAM : K-TOC (COMBINATION MODEL)
CROSS-VARIANCE
LAG

Fig. 9

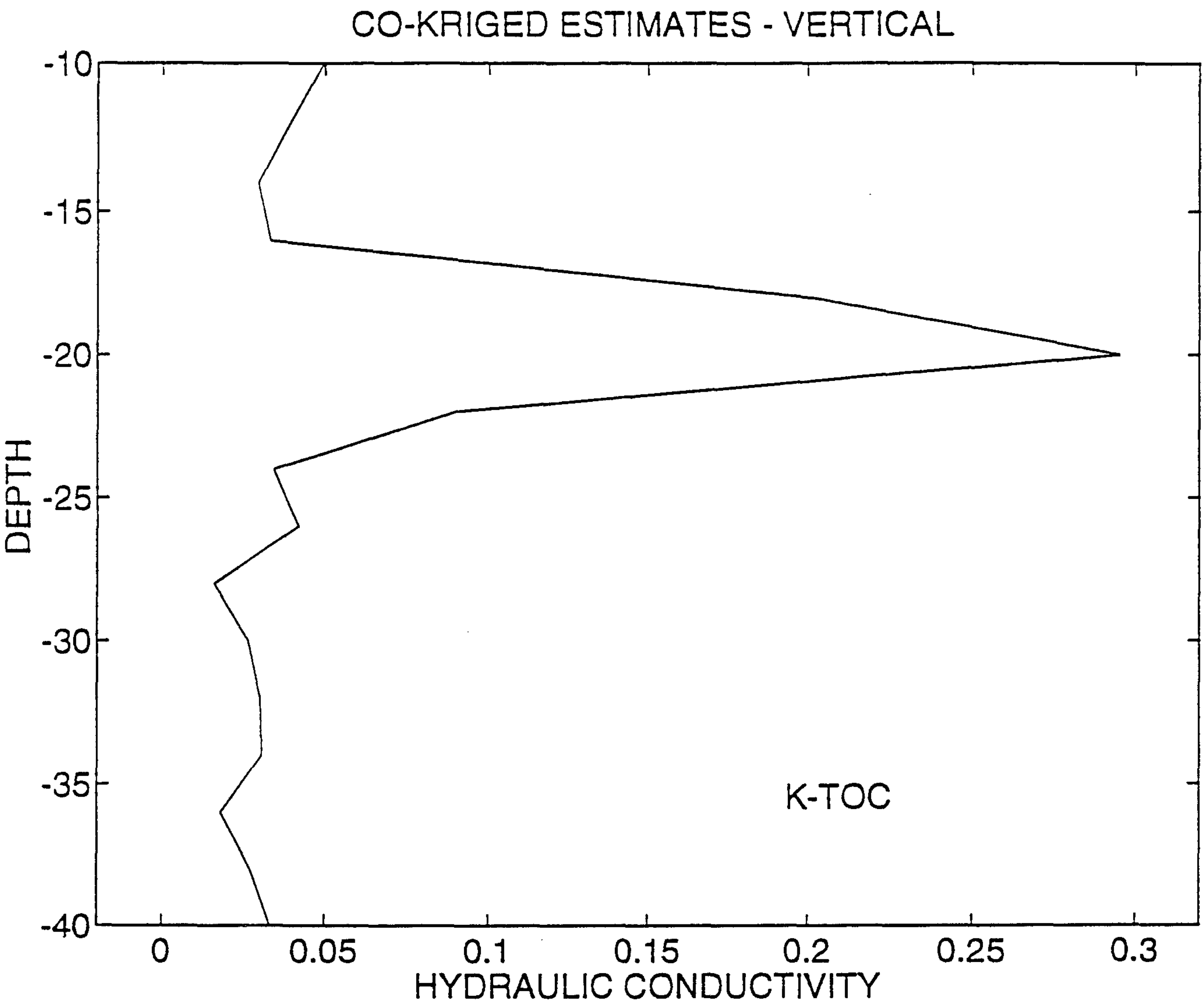

CO-KRIGED ESTIMATES - VERTICAL
DEPTH
-10
-15
-20
-25
-30
-35
-40
0
0.05
0.1
0.15
0.2
0.25
0.3
HYDRAULIC CONDUCTIVITY
K-TOC

Fig. 10

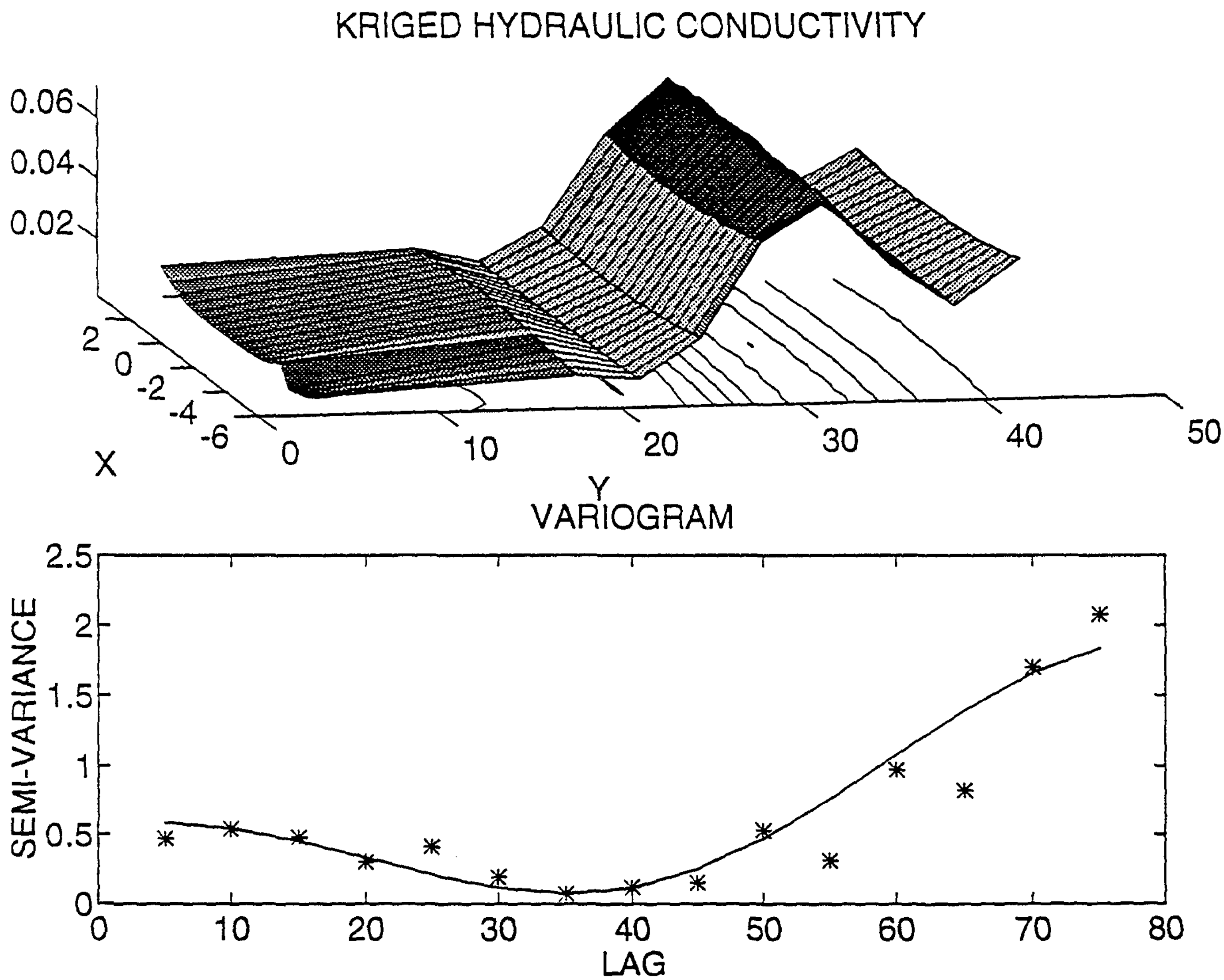

KRIGED HYDRAULIC CONDUCTIVITY
0.06
0.04
0.02
2
0
-2
-4
-6
X
0
10
20
30
40
50
Y
VARIOGRAM
2.5
2
1.5
1
0.5
0
SEMI-VARIANCE
0
10
20
30
40
50
60
70
80
LAG

Fig. 11

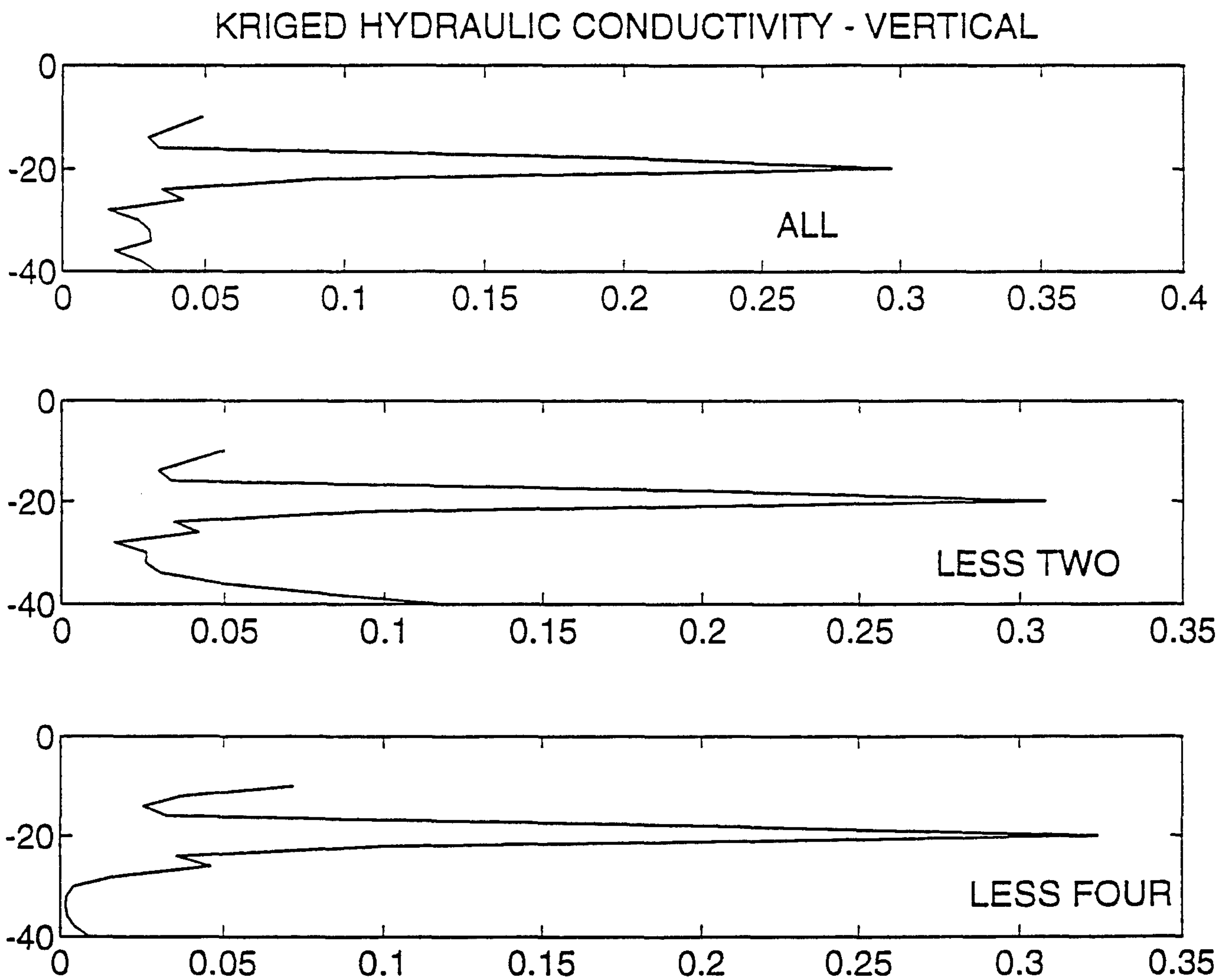

KRIGED HYDRAULIC CONDUCTIVITY - VERTICAL
0
-20
-40
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
ALL
LESS TWO
LESS FOUR

Fig. 12

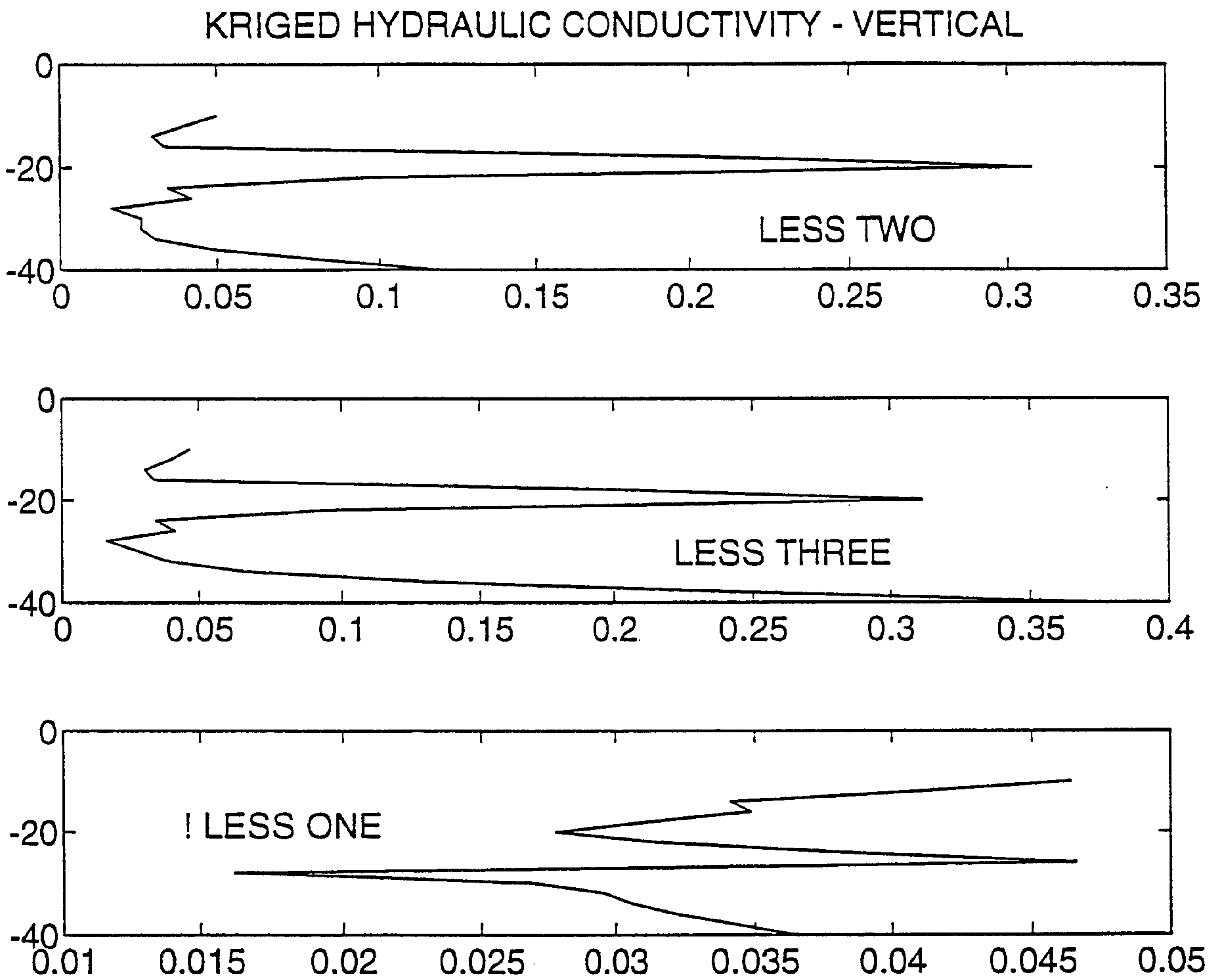
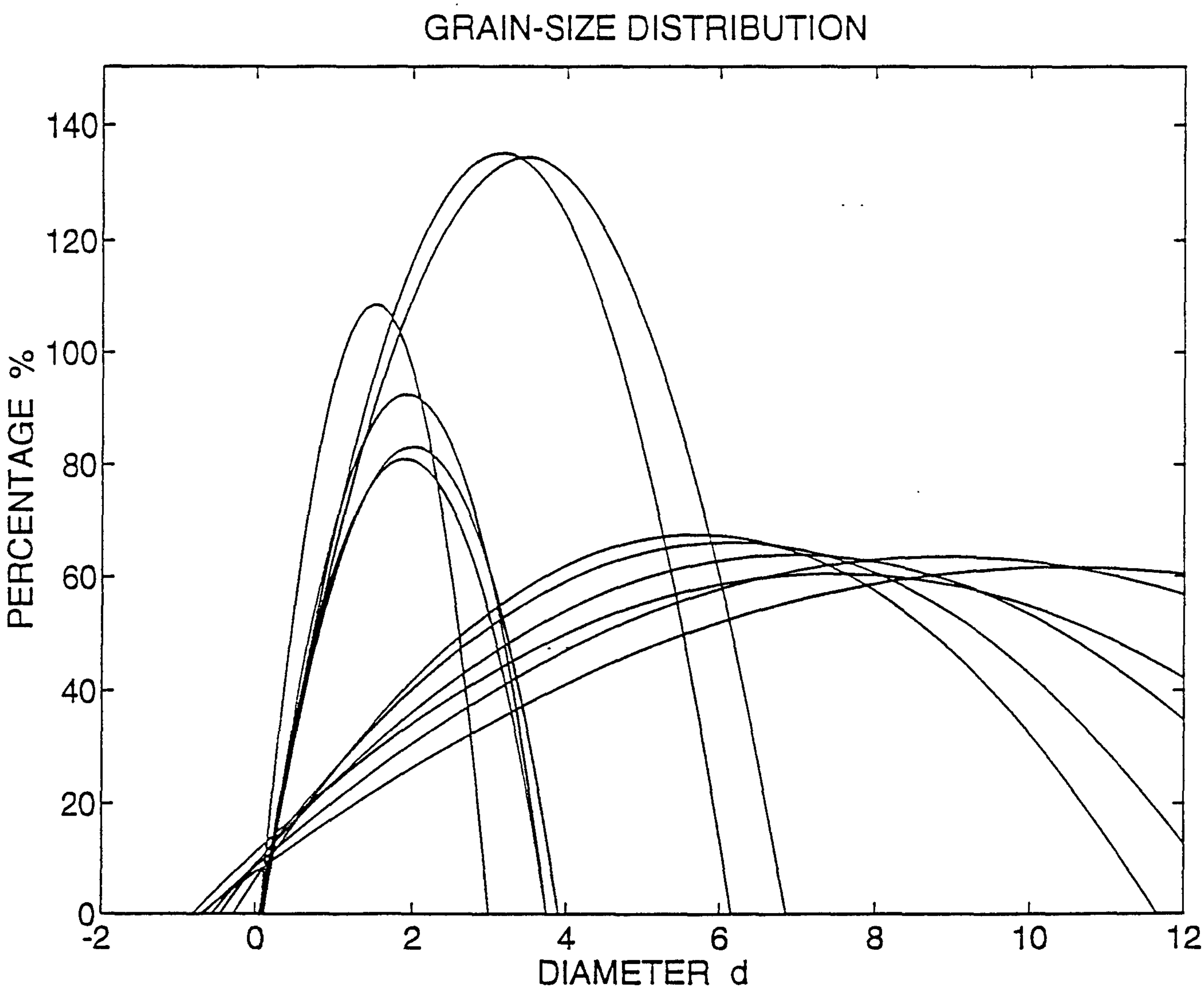

KRIGED HYDRAULIC CONDUCTIVITY - VERTICAL
LESS TWO
LESS THREE
! LESS ONE
0
-20
-40
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05

Fig. 13



GRAIN-SIZE DISTRIBUTION
PERCENTAGE %
DIAMETER d
0
20
40
60
80
100
120
140
-2
0
2
4
6
8
10
12

Fig. 14

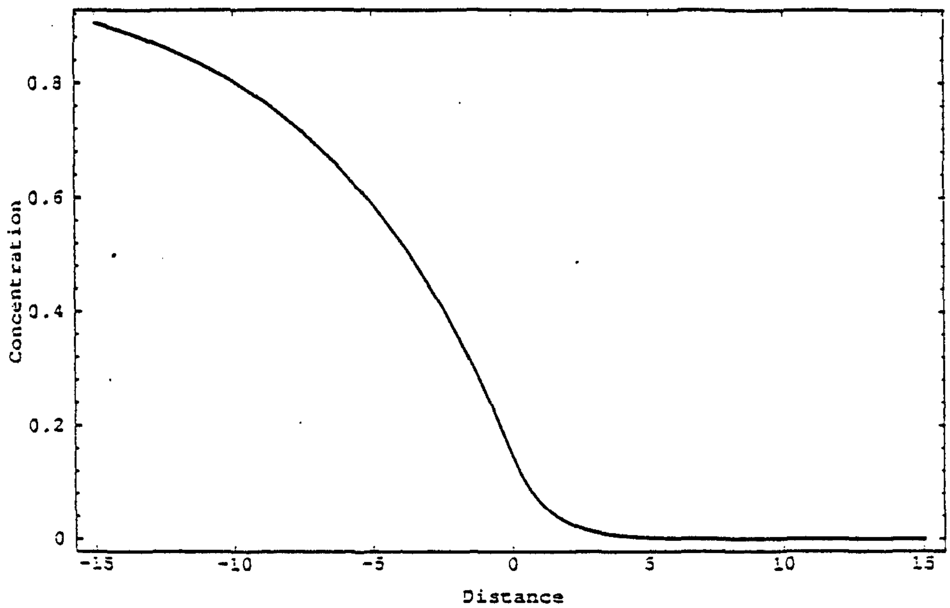


Fig. 15
'Freundlich Wave' from Linear Caricature

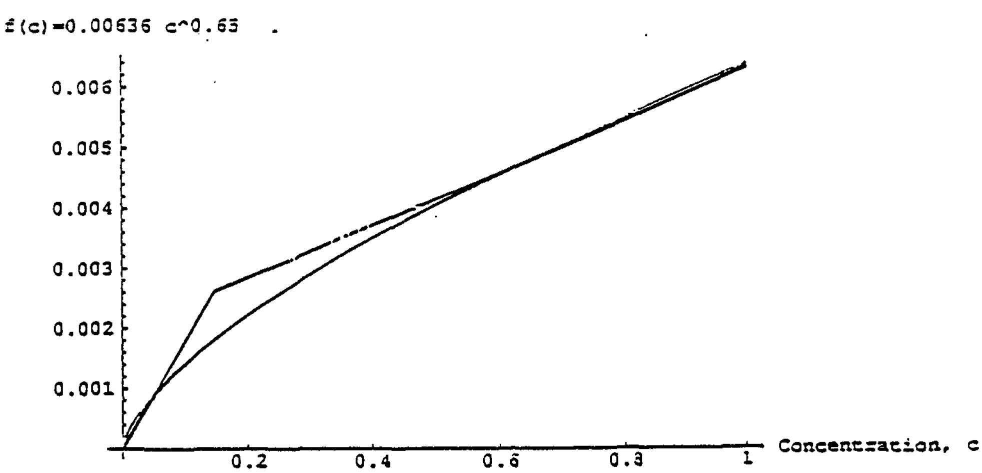


Fig. 16
Freundlich isotherm & a linear caricature

AN IMMOBILIZED-CELL FLUIDIZED-BED BIOREACTOR FOR 2,4-DINITROTOLUENE BIODEGRADATION

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Abstract

2,4-Dinitrotoluene (DNT) is a US EPA Priority Pollutant. *Pseudomonas* PR7 is able to completely degrade DNT via an oxidative pathway. Previous research showed that an immobilized-cell, recirculated packed-bed column reactor had high DNT removal activity but suffered from high pressure drops, channeling, and mixing problems. In this project, a fluidized-bed bioreactor (FBB) was developed to overcome these problems.

As part of this work, a mathematical model of the intrinsic biodegradation kinetics was developed based on results of batch cultivations of free cells. This model incorporates the observation that consumption of DNT can proceed in two phases because the enzymes in the metabolic pathway are not coordinately induced.

A cocurrent, three-phase, biofilm fluidized bed bioreactor was constructed. Tracer tests showed that the reactor was well mixed, and a biodegradation experiment indicated that the fluidized bed reactor performed as well as the packed bed system even though the FBB contained fewer immobilized cells.

AN IMMOBILIZED-CELL FLUIDIZED-BED BIOREACTOR FOR 2,4-DINITROTOLUENE BIODEGRADATION

Kenneth F. Reardon

INTRODUCTION

Many hazardous organic pollutants can be degraded to innocuous compounds by microorganisms. This concept forms the basis for the set of technologies called "bioremediation", of which two major types can be identified: *in situ* bioremediation, in which the contaminated soil and water is treated without being moved, and bioreactor treatment, in which microorganisms contained in a reactor are used to treat flows of contaminated soil and/or water. For the cleanup of large areas or deep aquifers, in situ bioremediation approaches are often better; however, soil-wash streams, industrial waste streams, and some aquifers are more appropriately treated in bioreactors.

In this project, two aspects of the biological treatment of 2,4-dinitrotoluene using the bacterium *Pseudomonas* PR7 were studied: the intrinsic kinetics and the design of an immobilized-cell, fluidized-bed bioreactor.

BACKGROUND

A. 2,4-Dinitrotoluene

2,4-Dinitrotoluene (DNT) is an EPA priority pollutant that is found in wastes from the manufacture of 2,4,6-trinitrotoluene (TNT) and toluenediisocyanate. Treatment of DNT-containing waste by activated sludge processes is usually difficult because of the high toxicity of this compound to most microorganisms. This problem is especially significant when there are fluctuations in the DNT concentration entering a treatment plant. Periods of high inlet DNT levels inhibit the growth of the DNT-degrading cells in the reactor and a significant proportion of them may be washed out, lowering the ability of the system to remove DNT. When the inlet concentration increases again, the concentration of DNT-degraders is too low to remove DNT to the desired concentration.

DNT has a molecular weight of 182.13 and its solubility in water is 1438 mM at 22 °C(1).

B. Microbial Degradation of DNT

2,4-DNT can be biodegraded by both oxidative and reductive pathways. The Microbiology Group of HQ AFCESA, Tyndall AFB has isolated three strains that utilize DNT as their sole source of carbon and energy via an oxidative metabolic pathway (*Pseudomonas* DNT-1, *Pseudomonas* PR7, and *Pseudomonas* R34). The pathway by which DNT is metabolized by these microorganisms has been determined (Figure 1)(2, 3).

The initial step in this pathway is an attack on DNT by a

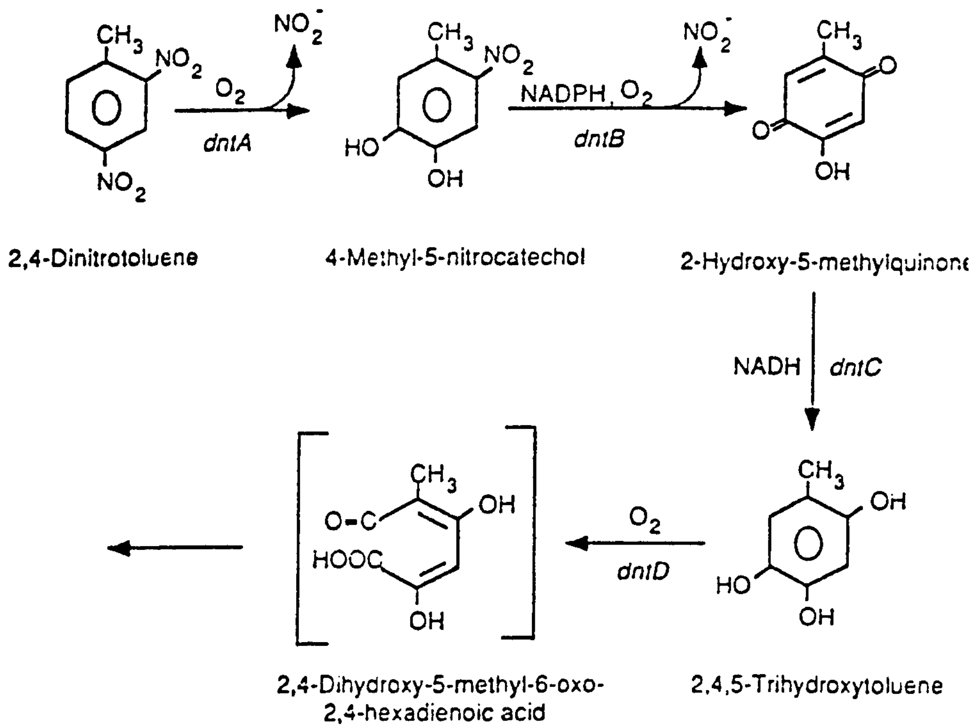

Figure 1. Proposed oxidative metabolic pathway for DNT degradation by *P.* sp. DNT(2); *P.* PR7 appears to utilize the same steps.

dioxygenase which results in the release of one nitrite group, and the formation of a yellow intermediate, 4-methyl-5-nitrocatechol (MNC)(3). A monooxygenase then catalyzes the oxidation of MNC to 2-hydroxy-5-methylquinone (HMQ) and nitrite. A quinone reductase and 2,4,5-trihydroxytoluene oxygenase catalyze further reactions to result in colorless ring fission products(2).

Other microorganisms degrade DNT reductively to amino and azoxy or nitroso compounds, but the reduction products are

difficult to degrade further(4, 5, 6).

It has been reported that *Phanerochaete chrysosporium*, a lignin-degrading fungus, degrades DNT to carbon dioxide and water by first reducing one nitro group to an amine, and subsequently removing both nitro groups via reactions involving peroxidase enzymes(7).

C. Overview of Bioreactors

Bioreactors may be divided into those containing either free (suspended) cells or immobilized cells (retained within the reactor). Both reactor types can be operated in batch, fed (or sequencing) batch, or continuous flow modes. For biotreatment of waste streams, continuous-flow reactors are desirable because they require no fill and drain time.

Continuous reactors are further characterized by the type of mixing involved, expressed on the continuum from perfectly mixed to perfectly unmixed (plug flow). The degree of mixing can be determined experimentally and analyzed via the residence time distribution(8).

The most common type of continuous, free-cell bioreactor is the continuous stirred-tank reactor (CSTR). While these reactors are relatively straightforward to design and operate, their use is always limited by the specific growth rate of the microorganisms serving as the biocatalyst. This occurs because the governing equation for a steady-state CSTR is $\mu = D$, where μ is the specific growth rate and D is the dilution rate (flow rate divided by volume), and thus the maximum flow rate for a given system is dictated by the rate at which the cells are able

to grow; excessive flow rates lead to washout of cells from the reactor vessel. Microbial growth rates on most organic pollutants are slow and thus this constraint is a significant one. A further disadvantage of most free cell reactor systems used in wastewater treatment is that the low concentrations of carbon sources (pollutants) in the feed streams can support only small populations of cells, resulting in a low volumetric reactor productivity (amount compound degraded/reactor volume/time).

Immobilized-cell bioreactors, in which cells are confined within a reactor by attachment to the surface of small particles, entrapment within a porous polymer, flocculation, or retention behind a membrane. Using these techniques, it is possible to obtain high cell concentrations in a reactor and thus provide a higher volumetric productivity than comparable free cell systems. In addition, the feed rate of continuous-flow, immobilized-cell reactors is not restricted by the specific growth rate of the cells (since they are retained within the reactor).

Three major types of immobilized cell bioreactor have been identified: stationary surface reactors (e.g., packed bed), moving surface reactors (e.g., rotating biological contactor), and mixed particle reactors (e.g., fluidized bed bioreactor)(9). Since moving surface bioreactors have lower surface area-to-volume ratios, they generally have lower volumetric activities than the other two types. Stationary particle (packed bed) bioreactors can have high volumetric activities and are relatively simple to operate; however, excessive cell growth can

obstruct fluid flow and removal of gas bubbles can be difficult. Large pressure drops over the column can only be avoided by using large diameter, rigid supports (surface immobilization), which have larger void volumes and thus lower the volumetric activity. Continuous-flow packed bed reactors are frequently operated in a single-pass mode that approximates a plug-flow reactor (PFR). Alternatively, the packed-bed reactor can be operated in a recycle mode that approximates a CSTR system(10). While the PFR system is simpler and can result in an effluent containing very low levels of contaminant, problems can arise owing to the lack of mixing along the column. Specific problems of this type are oxygen limitations, pH gradients, and substrate or product inhibition(10). In the packed-bed CSTR system, these problems are avoided because the feed is diluted when it is mixed with the liquid content of the system. However, a zero concentration of contaminant in the effluent from a CSTR is not possible since this stream has the same composition as the liquid recirculating in the bioreactor. It can be shown that a reactor system consisting of a CSTR (in which the contaminant concentration is reduced from a high to a relatively low level) followed by a PFR (in which the contaminant concentration can be reduced to a very low or zero concentration) results in the highest overall volumetric productivity(8).

A major drawback of the packed-bed, recycle (pseudo-CSTR) system described above is the high recycle flow rate required to achieve mixing. These high flow rates lead to high pressure drops over the column length and thus require larger pumps. In addition, surface immobilized cells (the least expensive

immobilization type) may be sheared from their support when exposed to high liquid flow rates.

Mixed particle bioreactors, on the other hand, utilize small particles that are suspended and mixed by upflowing gas and/or liquid, thus eliminating problems faced by packed bed bioreactors. This type of reactor can span the mixing range from plug flow (expanded bed operation) to well mixed flow (fluidized bed operation). Mixed particle bioreactors have been successfully applied to the treatment of various wastewaters (e.g., phenol(11, 12, 13), 3,4-dichloroaniline(14)).

D. Previous Results with Bioreactors for DNT Degradation

Removal of 2,4-DNT from aqueous solutions has been achieved in an immobilized-cell bioreactor system containing immobilized *Pseudomonas* PR7(10). The bioreactor system consisted of a packed column recirculation system that emulated a CSTR. The column contained diatomaceous earth pellets to which the microorganisms were attached. The feed to the system contained 2,4-DNT (from 500 to 1200 mM) as the sole carbon source in a minimal medium containing phosphate, ammonium, and other nutrients. During a 712-hour test of this bioreactor, various studies were carried out to characterize the system. The maximum performance was 325 μmol/L·h (based on total liquid volume) or 470 μmol/L·h (based on the column volume). The comparable rate in a continuous suspended cell reactor was 25 μmol/L·h. The bioreactor also demonstrated resistance to large perturbations and the ability to function stably for long

periods.

Although this packed bed bioreactor system performed well, several problems were noted: (1) gas bubbles accumulated in the interstitial spaces in the column, leading to flow channeling and inefficient use of the reactor volume; (2) at the high dilution rates that could be used with the system, the liquid velocity in the column required to maintain CSTR-like behavior was very high; (3) mixing for pH control was found to be important. The second of these concerns is especially important for bioreactor scaleup.

E. Design and Analysis of Fluidized Bed Bioreactors

1. General Aspects

Fluidized Bed Bioreactor (FBB) design is more difficult than that of most other bioreactor types because fluidization phenomena are complex and not well characterized. These issues are discussed in many journal reports and books(15, 16). In general, however, the characteristics most important for a FBB employing surface-immobilized cells (biofilms) are:

Particle attributes

Size and density are the most important particle characteristics because they are directly related to the amount of biocatalyst in the reactor (i.e., surface area), the minimum fluidization velocity (see next section), and the maximum liquid velocity (and thus the maximum aeration rate and minimum residence time). Other particle features (angularity, size distribution, etc.)

are also important(17).

Liquid velocity in column

While the range of permissible liquid velocities is dictated by the particle characteristics, the chosen operating velocity influences the type of fluidization, the biofilm thickness (via shear effects), the liquid film mass transfer coefficient, and the pressure drop.

Reactor characteristics

There are several types of FBB. Although the most common shape is cylindrical, especially for large scale systems, tapered reactors have also been utilized(18). Other variations include the presence or absence of external downcomers and internal draught tubes. Reactors can be operated as 2-phase (liquid-solid) or 3-phase (gas-liquid-solid) systems, and liquid flow can be co- or counter-current to the gas flow(13). An especially important reactor attribute is the angle of column inclination, which can affect the particle-liquid mass-transfer coefficient by up to 30% at 1.5 °(19).

2. Particle Fluidization

The minimum fluidization velocity U_{mf}, can be predicted through correlations derived from equations for the pressure drop across a packed bed. One correlation, based on estimations involving the particle shape factor Φ_p and the particle void fraction or porosity at minimum fluidization ε_{mf} that hold for many fluidized systems, is(20):

$$N_{Re,mf} = [(33.7)^2 + 0.0408 D_p^3 \rho_l (\rho_s - \rho_l) g/\mu^2]^{0.5} - 33.7$$

where

$$N_{Re,mf} = D_p U_{mf} \rho_l/\mu$$

Rearranging the definition of $N_{Re,mf}$ yields

$$U_{mf} = N_{Re,mf}\mu/D_p\rho_l$$

where $N_{Re,mf}$ = particle Reynolds number at minimum fluidization, D_p = diameter or effective diameter of particles, U_{mf} = minimum fluidization velocity of the liquid, ρ_l = density of the liquid, ρ_s = density of the solids, μ = viscosity of the liquid. For liquid-solid-air fluidized beds, the following correcting equation was developed by Song et al.(20):

$$U_{lmf}/U_{lmfo} = 1 - 0.376 U_g^{0.327} \mu_l^{0.227} D_p^{0.213} (\rho_s - \rho_l)^{-0.423}$$

which is valid for the following conditions:

$$0 \le U_g \le 17 \text{ cm/s}$$
$$0.9 \le \mu_l \le 11.4 \text{ centipoise}$$
$$0.046 \le D_p \le 0.63 \text{ cm}$$
$$1.8 \le \rho_s \le 2.5 \text{ g/cm}^3$$

U_{lmfo} is calculated using the two-phase (liquid-solid) equation

above, and U_g is the superficial gas velocity.

The pressure drop at the minimum fluidization velocity is equal to the weight of particles in the bed(20):

$$\Delta P = (\rho_s-\rho_f)\ (1-\varepsilon_{mf})L_o$$

where

ρ_s = density of the solid particles

ρ_f = density of the fluid

ε_{mf} = voidage, or void fraction in the solids bed at minimum fluidization

L_o = height of fixed solids bed before fluidization starts

Once fluidization occurs, the pressure drop remains nearly constant as the liquid flow increases(20).

3. Fluidized Bed Bioreactor Design

The design of a FBB begins with the choice of 2- or 3-phase system. For bioreactors based on aerobic microorganisms, oxygen must be supplied and this can be done at a much higher rate in a 3-phase reactor than by pre-aerating the liquid feed to a 2-phase reactor. However, the increased agitation caused by gas bubbles results in higher shear forces that can damage particles and/or biofilms.

The fluidization regime must also be chosen (Fig. 2). Most FBBs for treatment of pollutants are operated in the

bubbling/slugging or expanded bed (lower gas velocity; not shown) regimes. The choice between these is primarily determined by the type of mixing desired: expanded beds are closer to plug flow, while bubbling beds (and more agitated varieties) are more perfectly mixed. In general, the liquid-film mass transfer resistance decreases as particle motion increases.

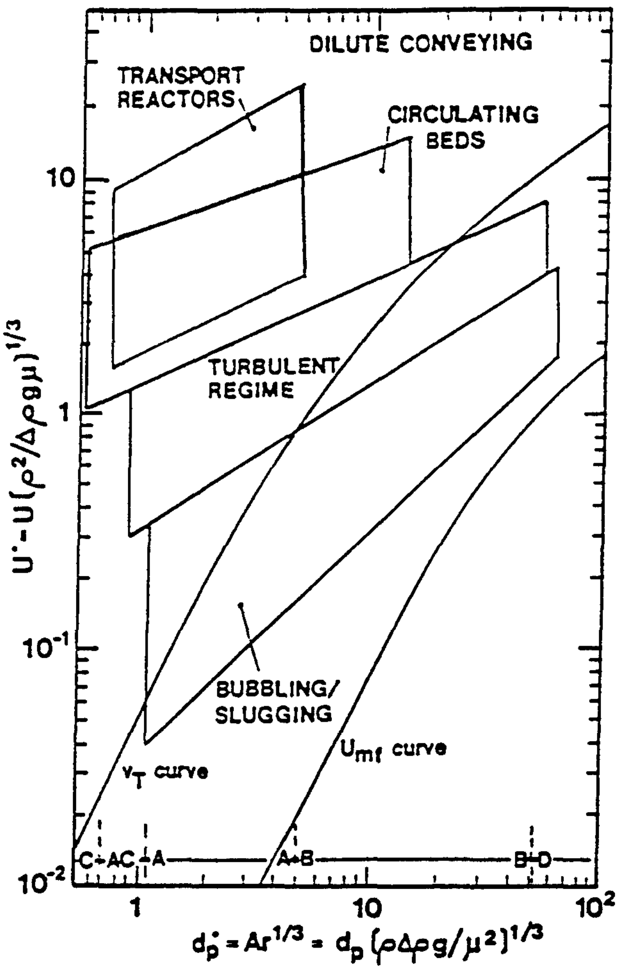

Figure 2. Regime map showing dimensionless gas velocity (U*) vs. dimensionless particle diameter (d_p*). The curves for minimum fluidization (U_{mf}) and terminal settling velocity (V_T) are also shown(17).

Once these characteristics have been decided, the allowable ranges of particle density, size, and liquid (and gas) flow rates can be determined.

The mathematical description of a FBB depends strongly on the type of system chosen and the degree of detail desired. Whether explicitly or by assumption, a model must consider the following:

- liquid-phase mixing
- solid-phase mixing
- intrinsic reaction kinetics for all possible limiting substrates (typically the pollutant compound and oxygen)
- mass transfer (liquid-film, biofilm, and/or intraparticle)

PROJECT GOALS

The goal of this research project was to investigate the application of a bioreactor containing immobilized *Pseudomonas* PR7 for the remediation of 2,4-DNT-contaminated water. This was accomplished by efforts in two areas:

- Measurement and modeling of the intrinsic biodegradation kinetics

- Construction, testing, and modeling of an immobilized-cell fluidized-bed bioreactor

MATERIALS AND METHODS

A. Materials

Microorganism

Pseudomonas PR7, isolated by the Microbiology Group of HQ AFCESA at Tyndall AFB, was selected for use in the fluidized bed bioreactor in order to compare this reactor type with previous research using this strain in a packed-bed bioreactor(10). This strain exhibits high overall and specific DNT consumption rates and accumulates only low levels of MNC for relatively short times in batch culture.

Media

All liquid cultivations of *P.* PR7 were carried out in solutions of DNT in Spain's Mineral Salts Base (SMSB), which contains (mg/L): $MgSO_4 \cdot 7H_2O$, 112.5; $ZnSO_4 \cdot 7H_2O$, 5.0; $Na_2MoO_4 \cdot 2H_2O$, 2.5; KH_2PO_4, 340; $Na_2HPO_4 \cdot 7H_2O$, 670; $CaCl_2$, 13.8; $FeCl_3$, 125; NH_4Cl, 500.

The strain was maintained on plates containing SMSB, 500 mM DNT, and 15 g/L Bacto agar (Difco) or on plates made from tryptic soy broth (Difco) (3.75 g/L), 500 mM DNT, and 15 g/L Bacto agar.

B. Analytical Methods

Dinitrotoluene Concentration

The concentration of DNT was determined by high pressure liquid chromatography (HPLC). Separations were achieved on 4.6 x 150 mm Rainin Microsorb type C8 column with 5-μ particle size and 100-Å pore size as the stationary phase and a 1.0 mL/min gradient of acetonitrile and acidified water (0.008N H_2SO_4) as the mobile phase. The column was protected by a 5-μm Microsorb C8 precolumn. The injection volume was 20 μL. The elution gradient program began with 10% acetonitrile/90% aqueous trifluoroacetic acid for 4 minutes, followed by an increase to 50% acetonitrile over 1 min, where it was held for an additional 10 min before a second concentration ramp to 85% acetonitrile over 1 min. This concentration was maintained for 9 min to complete the elution. Eluted compounds were detected at 254 nm by a Millipore Waters 486 Tunable Absorbance Detector.

The sample queue, injection volume, solvent gradient were controlled by a Maxima 820 Chromatography Workstation. Calibration curves and integration of chromatograms were also performed using the Maxima Workstation. Aqueous solutions of DNT were periodically made up in 100-μM increments from 100 μM to 1000 μM and used as standards for calibration.

Nitrite Concentration

Nitrite concentrations were measured using the sulfanilic acid/sulfanilamide method(21).

Free Cell Concentration

The concentration of free (suspended) cells was estimated by measuring the optical density at 600 nm in a spectrophotometer with deionized water as the blank.

C. Experimental Protocols

Shake Flask Cultivation

Batch experiments were performed using 200 mL of 500, 750, or 1000 μM initial DNT concentration plus Spain's Mineral Salts Base (SMSB) solution in shake flasks incubated at 30 °C at 200 RPM. The shake flasks were inoculated with 20 mL of a *P.* PR7 culture in exponential growth. The cultures used for inocula were from shake flasks with 1000 μM DNT initial concentration, incubated at 30 °C at 200 RPM for 100 h or until the yellow color disappeared.

Samples were taken with sterile 10-mL pipettes in a laminar

flow hood. An unfiltered portion of each sample was used for cell concentration measurements. The remainder was immediately filtered through a 2 μm syringe filter to separate cells and stop degradation activity. Filtered samples were analyzed for NO_2^- concentration, DNT concentration, and pH.

Fluidized Bed Bioreactor

The construction of the FBB is covered in the Results and Discussion section. The protocols for the mixing and biodegradation experiments are described in the following paragraphs.

Mixing Experiments

Residence time distribution analysis was performed using sodium chloride as a tracer. Chloride ion concentrations were measured with Orion chloride ion and reference probes, a conductivity meter calibrated in millivolts, and a chart recorder. Instruments were calibrated with sodium chloride solutions from 0 to 200 mg/L in deionized water. The FBB was filled with deionized water and Manville Celite R-630 particles and fluidized with air and recirculated water. Deionized water was pumped through the reactor at a dilution rate of 0.30 h^{-1} for a short time to establish steady fluidization conditions. The feed was then switched to a 150 ppm NaCl solution and conductivities were recorded until reactor concentration reached a maximum of 150 ppm NaCl (about 2 residence times).

DNT Biodegradation Experiments

The fluidized-bed bioreactor was loaded with 200 mL of

calcinated diatomaceous earth particles (Manville Celite R-630) and about 300 mL of 1000 μM DNT plus SMSB and autoclaved. Air was bubbled in the bottom of the vessel to provide oxygen. An inoculum of 10 mL of a culture of *P.* PR7 (grown in a solution of 1000 μM DNT initial concentration) in exponential growth was introduced through a septum near the bottom of the reactor. After inoculation, the bacteria were given 70 hours to begin exponential growth, 400 mL of 1000 μM feed was added, and bacteria were again given time to grow. Once MNC (indicated by yellow color) appeared and disappeared, feed was added at a slow rate and continued until the reactor was full. Liquid in the reactor was then recycled until the appearance of yellow MNC occurred after about 72 hours, which was used as an indicator of the initiation of growth soon to follow. Continuous feed was then started at a dilution rate of 0.31 h^{-1}, and the air rate was increased to between 1000 and 1100 cm^3/min.

The liquid capacity of the reactor was 1.7 L when loaded with solids, but this did not remain constant due to the sloughing of particle mass during fluidization. The reactor volume was taken as 1.7 L for the calculation of dilution rates.

The inlet DNT concentration to the reactor was 1000 mM and dilution rates varied from 0.031 to 0.14 h^{-1}. Samples were taken from the top and bottom of the column through septa to avoid contamination of the reactor. Filtered samples were analyzed for DNT, NO_2^-, and pH.

RESULTS AND DISCUSSION

A. Biodegradation Kinetics

1. Batch Cultivation Experiments

Batch shake flask experiments were performed using initial DNT concentrations of 500, 750, or 1000 μM at 30 °C. The results of these experiments are shown in Figures 3-5.

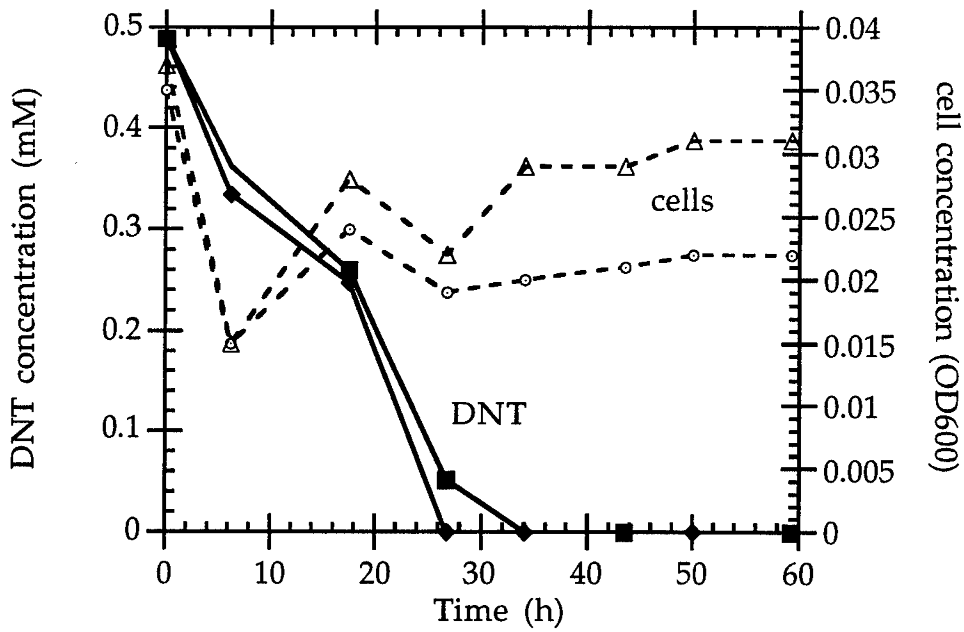

Figure 3. Results of replicate batch shake flask cultivations with 500 μM initial DNT.

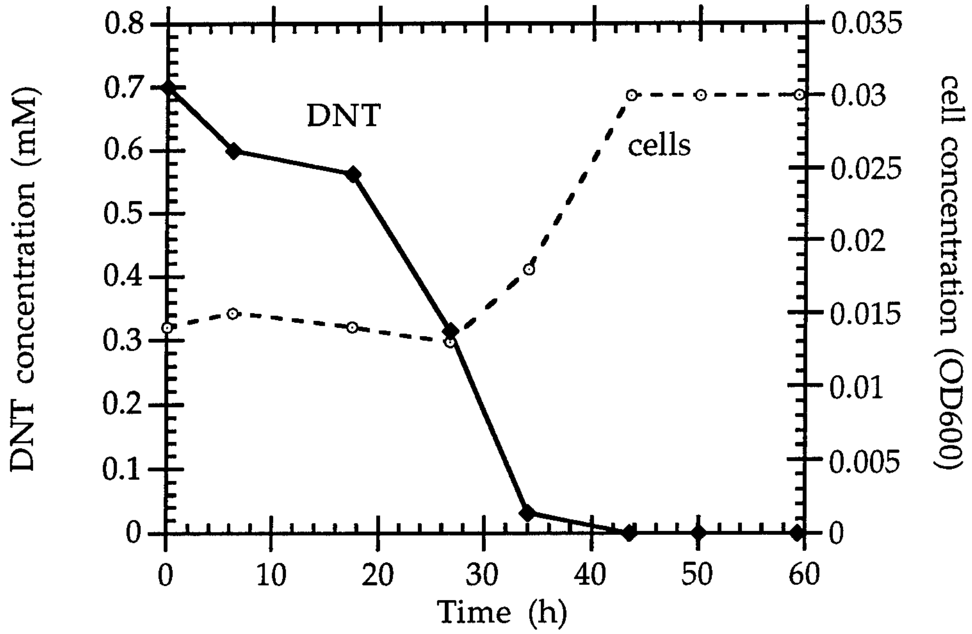

Figure 4. Results of batch shake flask cultivation with 750 μM initial DNT.

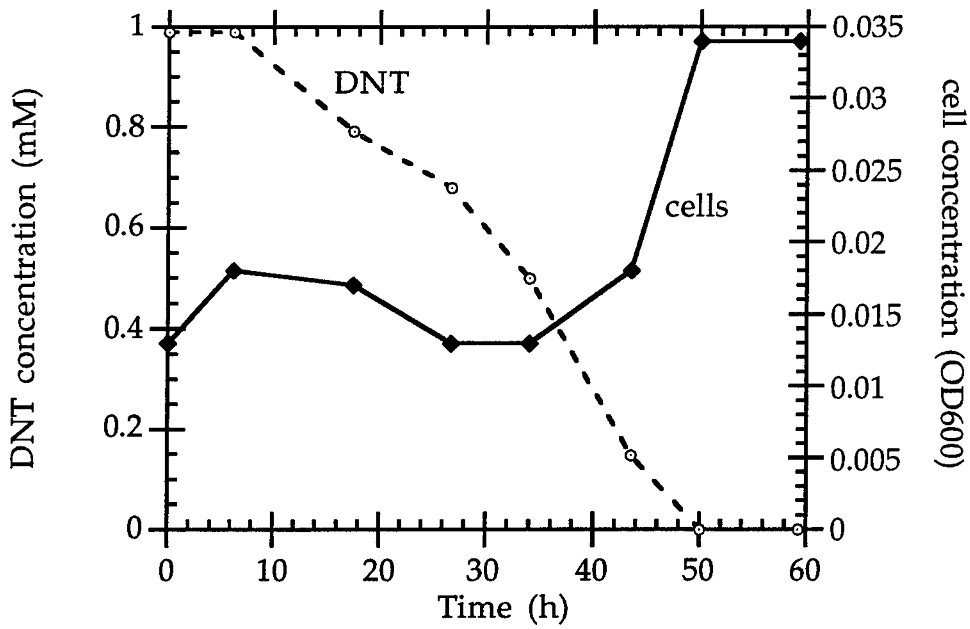

Figure 5. Results of batch shake flask cultivation with 1000 μM initial DNT.

The results shown in Figures 3-5 confirm earlier reports that *P.* PR7 can utilize DNT as its sole source of carbon and energy(10). The overall yield coefficient for growth, $Y_{X/S}$, is 0.23 OD600/mM DNT.

These results also point out that cell growth does not begin until several hours after the onset of DNT conversion. Although MNC concentrations were not measured, visual observations of the yellow MNC compound correlated the start of rapid cell growth with the time at which MNC levels began to decrease. In addition, nitrate concentrations typically increased in a biphasic manner (Figure 6). These observations will be discussed further in the next section.

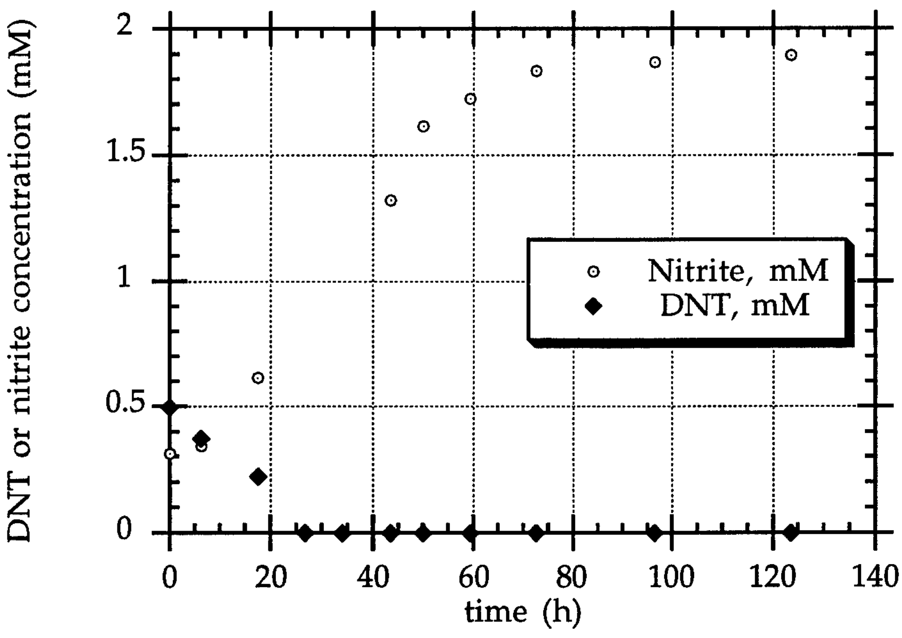

Figure 6. DNT and nitrate concentrations during a cultivation with 500 μM initial DNT concentration.

In this and previous research with this strain, pH decreases were observed due to the production of nitrite as HNO_2 (10). Higher buffer strengths could be used to control these pH changes, but it was important to determine the influence of the different ionic conditions on the metabolism of DNT. The results of a comparison of 1X- and 2X-buffered media are shown in Figure 7. The increased buffer levels had no appreciable effect on the cultivation.

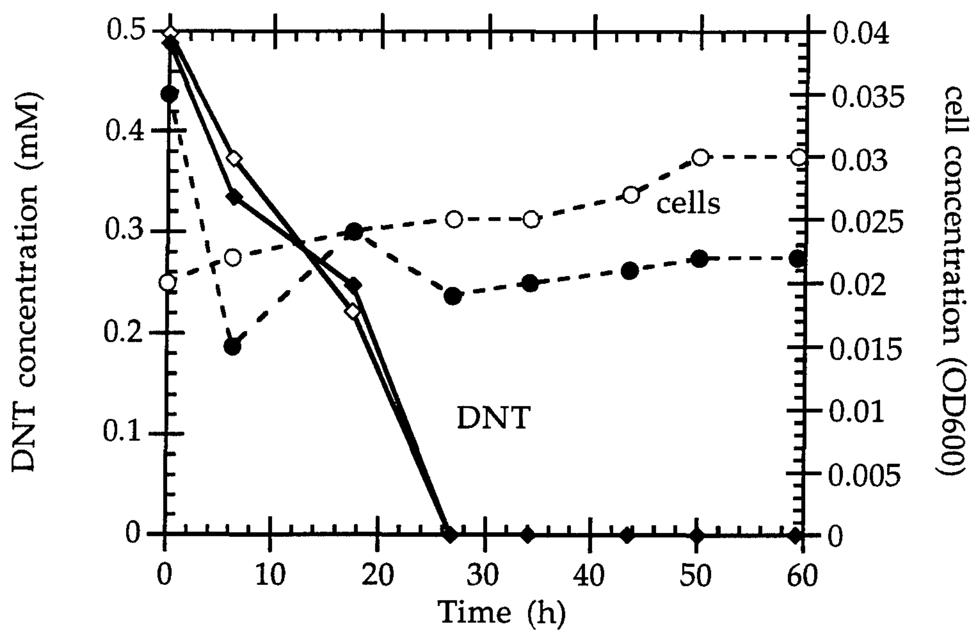

Figure 7. Effect of buffer strength on DNT metabolism and cell growth. Closed symbols: 1X buffer; open symbols: 2X buffer. Initial DNT concentration: 500 μM.

2. *Mathematical Modeling of Biodegradation Kinetics*

In previous research with *P.* PR7, the rates of cell growth and DNT consumption were obtained from CSTR cultivations and were found to be described well by the Monod model(22):

$$\mu = \frac{1}{X}\frac{dX}{dt} = \frac{\mu_{max}[DNT]}{K_S + [DNT]}$$

and

$$\frac{dS}{dt} = -\frac{\mu_{max}[DNT]X}{Y_{X/S}(K_S + [DNT])}$$

In these expressions, μ is the specific growth rate, μ_{max} is the maximum specific growth rate, X is the cell concentration, and K_S is the Monod constant. Quantities in brackets are concentrations. The values of μ_{max} and K_S were found to be 0.11 h^{-1} and 34 μM, respectively.

The expressions above show cell growth rate to be dependent on DNT levels. However, the results of the batch cultivations shown in Figures 3-7 and the visual observations discussed above imply that cell growth in batch culture cannot be described as a function of DNT concentration. Indeed, a study of the metabolic pathway (Figure 1) shows that no carbon or energy for cell growth is produced by the conversion of DNT to MNC. The transient appearance of MNC in the culture and the correlation between its appearance and the start of exponential growth indicate that cell growth rates are better described as a function of MNC concentration:

$$\frac{d[DNT]}{dt} = -\frac{k_D[DNT]E_D X}{K_D + [DNT]}$$

$$\frac{d[MNC]}{dt} = +\frac{k_D[DNT]E_D X}{K_D + [DNT]} - \frac{k_M[MNC]E_M X}{(K_M + [MNC])Y_{X/S}}$$

$$\mu = \frac{1}{X}\frac{dX}{dt} = \frac{k_M E_M [MNC]}{K_M + [MNC]}$$

$$\frac{dE_D}{dt} = \frac{E_{D,\max}[DNT]}{K_{E,D} + [DNT]} - k_{d,D}E_D$$

$$\frac{dE_M}{dt} = \frac{E_{M,\max}[MNC]}{K_{E,M} + [MNC]} - k_{d,M}E_M$$

$$\frac{d[NO_2^-]}{dt} = -\frac{d[DNT]}{dt} - \frac{d[MNC]}{dt}$$

In these equations, E_D and E_M are the amounts of DNT dioxygenase/cell and MNC monooxygenase/cell; k_D, k_M, $E_{D,max}$, and $E_{M,max}$ are rate constants; K_D, K_M, $K_{E,D}$, and $K_{E,M}$ are Michaelis-Menten-like constants; and $k_{d,D}$ and $k_{d,M}$ are decay constants. In this model, the degradation of MNC is presumed to be the growth rate-limiting step; if that were not true, an additional equation for another compound could be introduced and the equation for μ adapted accordingly.

This set of equations also reflects the fact that the pathway shown in Figure 1 is not coordinately induced in *P.* PR7. Interestingly, the major difference between the three strains known to use this pathway is in the genetic regulation of the pathway enzymes. For strain DNT, genetic analysis has shown

that the genes for the degradative enzymes are in three different operons(2). A comparison of strains PR7 and DNT has shown that MNC was accumulated to much higher levels for longer times in cultivations of strain DNT than in those of *P.* PR7(10). It is worth noting that the Monod equations are valid in the event that the entire metabolic pathway is induced, as might be expected in a steady state CSTR environment.

The values of the constants in the above cannot be determined from the batch experiments performed to date. A set of experiments in which intermediate (e.g., MNC) concentrations and enzyme activities are monitored must be performed to test this model.

B. Fluidized Bed Bioreactor (FBB)

1. Construction of Fluidized Bed Bioreactor

After careful study of FBBs that had been used by other researchers and consideration of the requirements for the P. PR7 system, we constructed a cocurrent, three-phase FBB (Fig. 8). This reactor has a liquid capacity of 1.6 L when loaded with support particles. There are sampling ports for both liquid and particles in the sides of the column that are used in mixing studies. The top of the reactor vessel contains ports for pH, pO_2, and temperature probes, as well as a vent for outlet gas and other inlet/outlet ports.

Some problems arose in the construction of this system, particularly with regard to the gas/liquid inlet region at the bottom of the reactor. This entry must be large enough to

accommodate the high flow rates required to fluidize the bed without causing high pressure drops across the entrance.

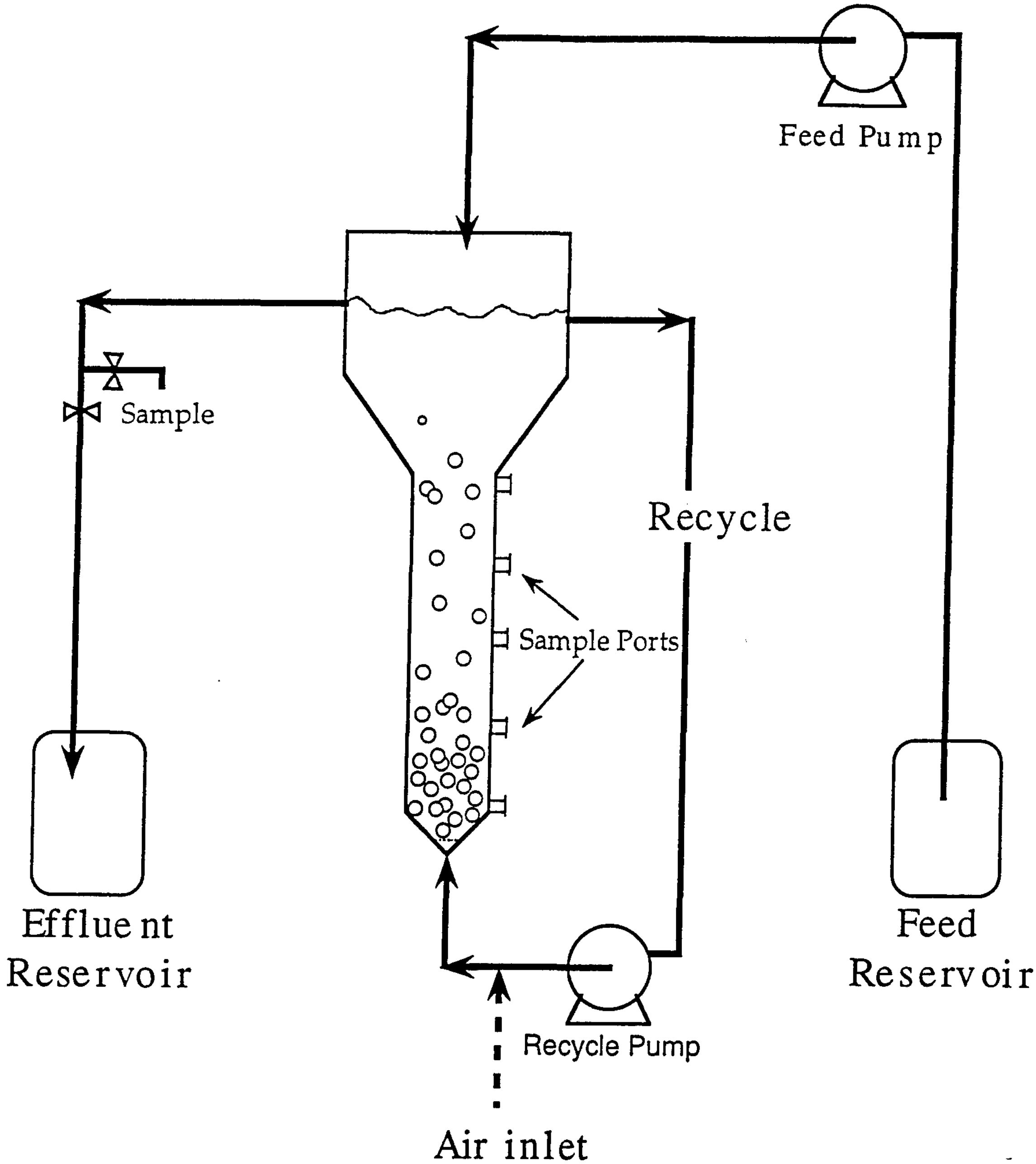

Figure 8. Schematic of the 3-phase, immobilized-cell fluidized-bed bioreactor system.

2. Fluidization Analysis

The fluidization equations presented in the Background section were used to determine the range of liquid velocities required to achieve fluidization ($U_{l,mf}$, the minimum fluidization velocity) for particles that were considered for use in the FBB. The results of this analysis are shown in Fig. 9.

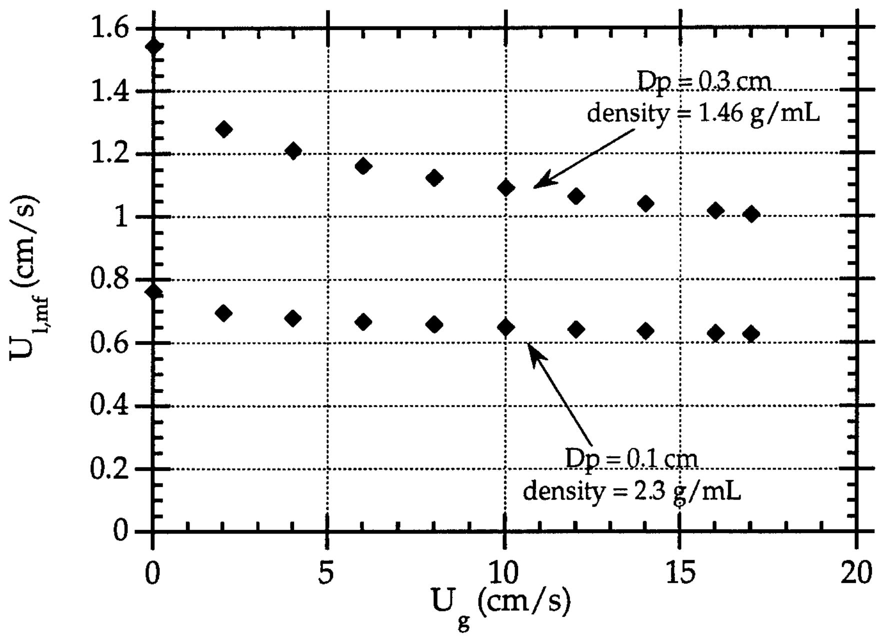

Figure 9. Minimum liquid fluidization velocity vs. superficial gas velocity for two support particles. The 3 mm diameter particles are Manville R-630.

3. Analysis of Fluid Mixing in FBB

Knowledge of the fluid mixing characteristics (e.g., perfectly mixed vs. plug flow) in a reactor is crucial to modeling its behavior. A step-change tracer test using chloride was performed on the FBB loaded with 200 mL of Manville R-630

particles without biofilm. The resulting output tracer concentration curve is shown in Fig. 10 (symbols). The predicted output if the liquid phase of this reactor were perfectly mixed (CSTR behavior) is shown in Fig. 10 as a dashed line. From this plot, it is apparent that the mixing in the FBB is not perfectly mixed; however, the mixing characteristics are much nearer those of a CSTR than a plug flow reactor. Further tracer tests will be conducted to investigate the effects of support loading and liquid velocity on the mixing characteristics.

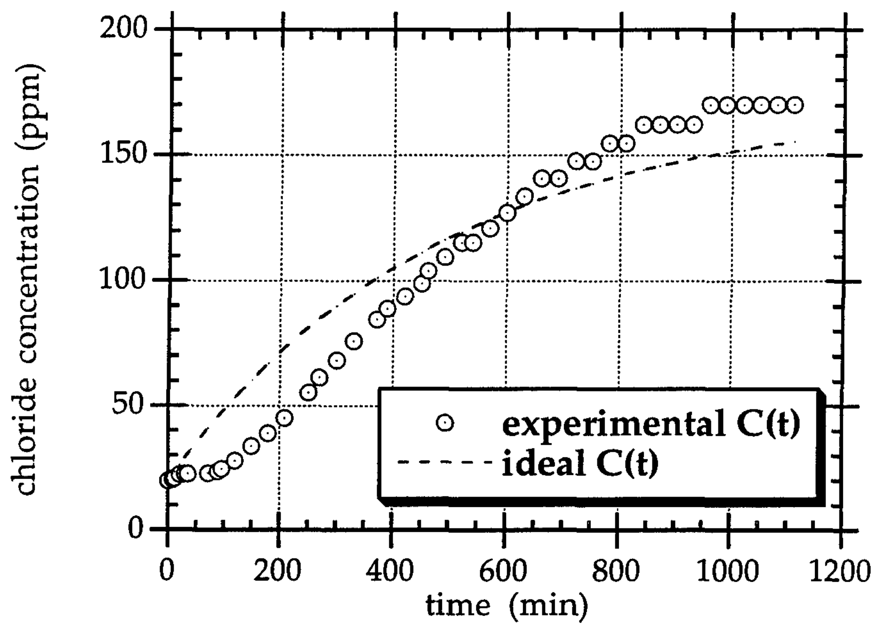

Figure 10. Results of tracer test to determine mixing characteristics. "Ideal" refers to perfect mixing.

4. DNT Biodegradation in the FBB

An experiment with the FBB was conducted using the protocol outlined in the Materials and Method section. The support particle chosen was Manville Celite R-630, a light, spherical diatomaceous earth particle. This support was used because its relatively low density allowed us to obtain fluidization at lower liquid and gas flow rates; for the same reason, only 200 mL of these particles were loaded into the 1.6 L reactor. The feed to the system contained 1000 μM DNT and two dilution rates were tested. The time course of the experiment is plotted in Fig. 11.

The results of this experiment were analyzed to show the performance of the reactor system (degradation rate per unit reactor volume vs. loading rate), and this performance curve was compared with those obtained in a previous study for a free cell CSTR and a recycle (pseudo CSTR) packed column system (Figure 12). Despite the very low amount of support particles in the reactor, the FBB performed as well as the packed column reactor over the loading range tested. Although it cannot be seen clearly from this plot, the free cell system had a maximum degradation rate of about 28 μmol/L/h, well below that of the immobilized cell bioreactors.

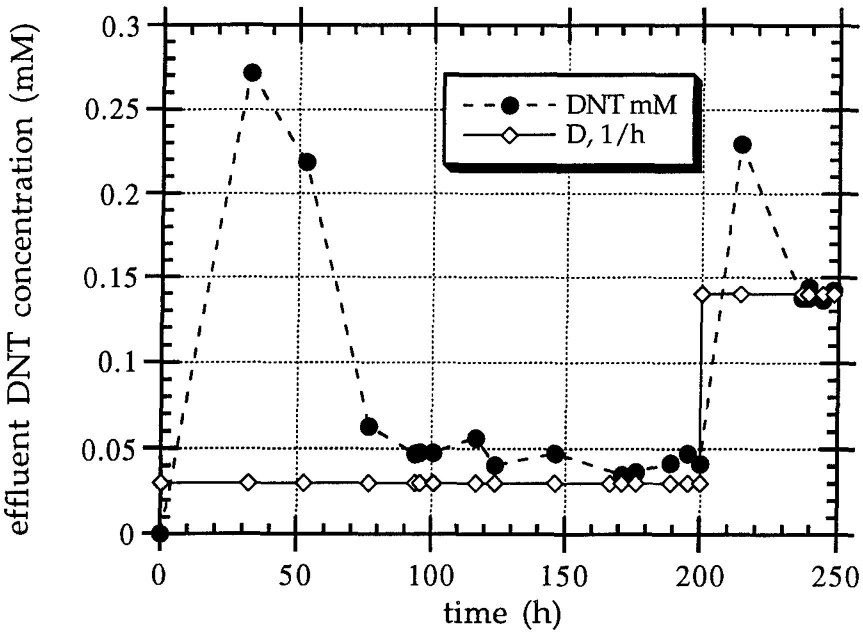

Figure 11. Time course of FBB experiment.

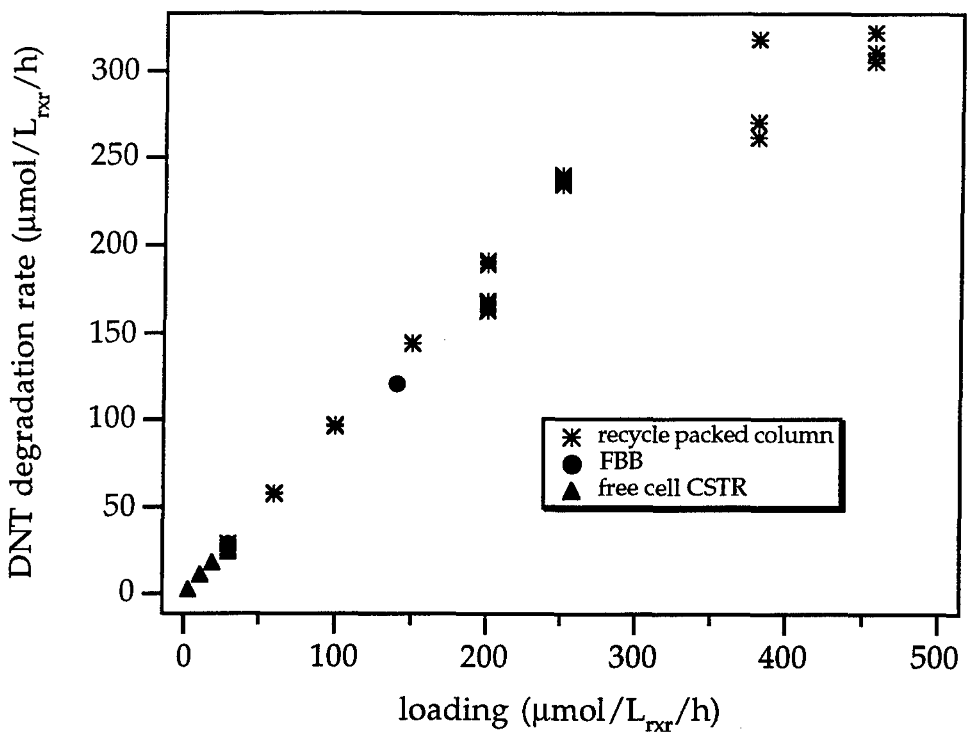

Figure 12. Comparison of performance of FBB run of Fig. 11 to other reactors(10).

CONCLUSIONS

The main goal of this work was to develop and model a fluidized bed bioreactor based on *Pseudomonas* PR7 for the removal of 2,4-dinitrotoluene from aqueous streams. In order to do this, a mathematical model of the biodegradation kinetics had to be established and verified through free cell experiments. The results of these two parts of this research effort can be summarized in the following points:

- Batch cultivations of free cells verified that *P.* PR7 can utilize DNT as its sole source of carbon and energy

- Batch growth on DNT proceeds in two phases: DNT is first consumed with the production of MNC but little or no cell growth; following this, MNC consumption and exponential cell growth begin. Differences in this pattern between strains can be attributed to variations in genetic regulation (pathway induction).

- A mathematical model was proposed to describe the observed unsteady state kinetics and included enzyme induction terms.

- A cocurrent, three-phase, biofilm fluidized bed bioreactor was constructed.

- The mixing characteristics of the FBB were tested and found to be similar to those of a CSTR.

- The results of a biodegradation experiment run in the FBB showed that the reactor had good performance relative to other free and immobilized reactors, despite a low particle fraction in the system.

This research work is continuing in our laboratory. Efforts are being directed toward verification of the mathematical model of the biodegradation kinetics. In addition, the FBB will be tested and characterized further and its performance limits ascertained.

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APPLICATION OF SUPERCONDUCTIVE DEVICES IN AIR FORCE

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Abstract

The objective of this research is to investigate the feasibility of superconductive devices in the Air Force. Three tasks have been completed: (1) to search for the latest materials on superconductive devices; (2) to study the needs of the Air Force; and (3) to evaluate the operation benefit in terms of the requirements in the Air Force. This report uses information from the following sources: (1) scientific publications; (2) reports from government agencies and industrial research institutes; (3) discussions with experts at universities, government agencies and industries; and (4) discussions with Air Force personnel. Following conclusions have been made: (1) Superconductive Magnetic Energy Storage (SMES) devices should be tested immediately; (2) Superconductive Generators of 1-10 MW should be developed as soon as possible; and (3) other devices such as motors and magnetic heat pump should also be developed.

APPLICATION OF SUPERCONDUCTIVE DEVICES IN AIR FORCE

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I. Introduction

Superconductivity was discovered in 1911, and high Tc superconductors were discovered between 1986 and 1993 [1-8]. Many different kinds of superconductive devices were designed and constructed [9-11]. In the past two years, WL/FIVCO had examined feasibilities of various superconductive devices for air base energy system applications [12-14]. In this project, three tasks have been conducted: (1) to search for the latest materials on superconductive devices; (2) to study the needs of the Air Force; and (3) to evaluate the operation benefit in terms of the requirement in the Air Force. This report uses information from following sources: (1) scientific publications; (2) reports from government agencies and industrial research institutes; (3) discussion with experts at universities, government agencies and industries; (4) discussion with Air Force personnel. This study includes following devices: Superconductive Magnetic Energy Storage (SMES) devices, Superconductive Generators, motors, and magnetic heat pumps.

II. SMES

II.1. Background

Superconducting Magnetic Energy Storage (SMES) is a device that can store energy in the form of magnetic energy. The stored energy can be easily converted to electrical energy by connecting a lead to the load or utility grid through a power conditioning system (PCS). In addition, small SMES devices are being used as power quality improvement devices to prevent sag and surge, to stabilize frequency and to improve other electrical properties.

The main components of a SMES, as shown in Figure 1 [15], are:

- Superconducting coils
- Cryogenic system (liquid helium bath)
- Power Conditioning System

Operation principles of SMES are rather straightforward. Figure 2 shows simple circuit diagrams of a SMES unit, assuming that a direct current power source is used. The cryogenic and power conditioning systems are not shown.

Figure 2a shows the unit in charging mode. The switch of power source is closed while persistent current and load switches are open. In this mode, electric current will flow from the power source to the superconducting

coil. When the superconducting magnet has reached its capacity, the persistent current switch is closed, and the load and the power source switches are opened. Figure 2b shows that the system is now in a storage mode, as shown in Figure 2b. In this mode, the current flow with zero resistance within the unit of the superconducting magnet. Ideally, the electrons will flow forever as long as the coil remains in a superconducting state. In other words the electric energy is stored. Figure 2c shows the unit in discharging mode. In this mode the load switch is closed, while the superconducting persistent current and power switches are open. The current stored in the superconducting magnet now flows to the load. The load can be a motor, light bulb or anything that requires s electric power. Not all energy stored in the SMES can be utilized. A minimum charge on the coil, usually assumed to be 10% of the total energy, must be maintained [16-19].

II.2. Economic Assessment

A Japanese group [20] studied the conceptual design of a 5 GWh SMES. The main purpose of the study was to confirm the project elements and to make an assessment of the cost of the units. They concluded that there are no significant technological problems of the SMES, and this technology has economically high potential. A cost analysis for a 10,000 MWh, 1000 MW system has been performed by Boom et al. [21]. They divided the cost as follows: 45% for the superconducting coil, 30% for rock preparation and structural insulator, 12% for on-site assembly, 8% for ac/dc converter and 5% for refrigeration units. The cost of infrastructure like building seems to be left out in this analysis. The cost of a SMES can be scaling with size, a feature that is not significant in other storage devices. The cost is approximately proportional to its surface area and the amount of superconducting coil used [22]. Also, the cost per unit of stored energy depends on the size of the SMES. As the size of the SMES gets larger, the cost per unit energy decreases [23].

A study performed by a team comprising of Bechtel, General Atomic, and EPRI [24] shows that the total capital cost for 5500 MWh, 500 MW SMES is about $ 1200 million [1982 $]. An extrapolation from Chemical Engineering Plant Cost Index [25] using 1982-1991 data, the total capital cost for this unit in 1993 would be $ 1510 million. (The 1982 index was 314 and the extrapolated index for 1993 was 395.3. The base line of 100 was established in the period of 1957-1959.)

II.3. General Application and Technical Status of SMES

The main purpose of using SMES is to stabilize power utility. The most important application would be load leveling to achieve a more constant system load. The stabilization of power utility could include the following items: peak power load reduction, power outage prevention, voltage sag prevention, frequency stabilization, etc. [26]. Some industries have been using pumped hydrostorage for load leveling purposes. However, hydraulic system is not as efficient as a SMES system. Due to its fast response, SMES can also be used to stabilize low frequency power oscillation in high voltage ac power lines.

For load leveling purposes, SMES has three operational modes. During low demand period, usually at night, the SMES is in the charge mode. In this mode the SMES absorbs the excess energy produced by the power source. When the supply is equal to the demand, the SMES is in standby or in a persistent current mode. In this mode the SMES functions as an energy storage device. When the demand is higher than the supply, then the SMES is in discharge mode. The energy stored in the coil is then delivered to the utility grid through a power conditioning system, which may include an ac-dc converter.

Investigation on SMES started about 30 years ago [27]. Since that time progress has been made. In the early 1970's the University of Wisconsin and the Department of Energy (DOE) started SMES research programs. SMES research activity was later performed by the Electric and Power Research Institute (EPRI) which studied technical and economic feasibility of a SMES.

A 30 MJ unit was tested for frequency stabilization by the Bonneville Power Administration in the early 1980's. However, no unit larger than 30 MJ has ever built and tested [28,29]. The EPRI and the DOE have sponsored conceptual designs for larger units, up to 5 GWh (18,000 GJ) of stored energy [28].

A 50 MJ testing plant has been constructed by a Japanese group [20] as a step toward commercialization. This unit is considered to be small, but the current and electromagnetic forces are large enough to speculate the properties of a larger unit. Ebasco Service, Inc. has studied a 22 MWh Engineering Test Model (ETM) SMES by dynamic simulation and showed that the performance of this model with the power conditioning system is technically feasible [30]. Bechtel Group, Inc. and General Dynamic Space System Division has designed a 20.4 MWh (73 GJ) SMES/ETM [31]. A detailed design was planned in 1991 and construction of the unit has not been carried out as of today. This unit would be the world's largest superconducting magnet ever built. Superconductivity, Inc. has produced and marketed small portable SMES units with capacities ranging from 460 kVA and 2500 kVA. The stored energy by individual unit ranges from 500 kJ to 2 MJ [32]. Although SMES technology is still very young, most researchers are optimistic that SMES units will be as feasible as other energy storage system.

II.4. Specific Application of SMES in the Air Force

U.S. Air Force needs of SMES units has been assessed by Wang [26]. He pointed out that the power grid problem in U.S. Air Force uses are much more serious than those of ordinary commercial purposes. To overcome the problems of power quantity and quality in the U.S. Air Force, utilization of SMES units could be one of the solutions [26].

The main purpose of using SMES in the U.S. Air Force is for load leveling and portable power storage. The storage capacity of the SMES for applications in the U.S. Air Force varies on its use. The largest unit will be for U.S. Air Force Base Power Supply. Wang has assessed SMES units for use in regular bases, bare bases, communication squadrons, air traffic control, sector operational control center (SOCC) radar stations, energetic

weapon and other areas. The size of SMES for these purposes would be in three ranges, i.e., 72 GJ, 100-500 MJ, and 1-20 MJ [26].

Which technology is best for the Air Force? At this moment two groups of materials are being considered for the superconducting coils, conventional low Tc and high-T_c superconductors. The low Tc superconductor, which is usually made of a metal alloy, has a lower superconducting transition temperature (T_c) requiring expensive liquid helium (boiling point 4 K) to be used as a refrigerant. High temperature superconductors, which are usually made of a ceramic oxide, offer some advantages over metal alloy superconductors, because less expensive liquid nitrogen (boiling point 77 K) can be used as a coolant. Also the heat that needs to be removed from the system is reduced. This will reduce the amount of liquid nitrogen required. However, a lot of problems must be solved before ceramic superconductors can be used as the superconducting magnet. Among the problems are low current carrying capacity, brittleness, processing difficulties and their vulnerability against applied magnetic fields. It has been known that the current density of high T_c superconductor is affected by magnetic fields. Some research has been performed to address this problem. Flux pinning mechanism and melt processing could reduce the effect of the magnetic field. While metal alloys can be easily shaped to form a wire, and bendable to almost any shape, this is not true for ceramic superconductors. Ceramic superconductors can be formed to produce a wire, but cannot be bent easily due to their brittleness. The most promising shape is probably a toroid.

Another benefit of high T_c superconductor, besides cryogenic systems, is the simpler thermal insulation required for liquid nitrogen over that for liquid helium. Direct advantages of high T_c materials on SMES expand to every part of the total system, except the power conditioning system. Matsuda and Shintomi predicted that the cost of high T_c SMES could be 30% lower than that of the low T_c SMES [27]. Loyd et al. [33] performed a calculation on the capital cost of both low and high temperature superconductors. They concluded that the total capital cost reduction when using high T_c superconductors would range from 7 -10 % for a plant of 20 - 5,000 MWh. Also, the operating cost could be reduced to about $ 500,000/year for a 5,250 MWh unit [33].

The choice of configuration may depend on the size and the site of the SMES. For large stationary SMES, such as for regular air bases power utility, a solenoid with low aspect ratio seems to be more feasible. The capital cost of this configuration is lower than that of other forms. The construction could be near a runway where there is no personnel that could be exposed to stray magnetic field. However, the stray magnetic field may affect the performance of the aircraft instruments. A further study on this subject is required.

For portable use, a toroid configuration seems to be preferable. The Lorentz force in this configuration is negligible. All magnetic fields are confined within the toroid. There are other options that could reduce stray magnetic fields such as even numbered solenoids [24,26] or solenoids joined at their ends [34]. From the feasibility studies on 5 GWh SMES plant, it was determined that no technical reason could prevent the commercialization of SMES [27]. (The study was done using NbTi and Nb_3Sn metal alloy superconductors.)

III. Generator

III.1. Background

Superconductors are very attractive to electric machinery because they are capable of lossless conduction, and they have an ability to carry very large current densities and produce high flux densities. This allows for the elimination of magnetic iron, which in turn dramatically reduces the size and weight of the machine, and offers other advantages that will be discussed in section III.4.

Most researchers agree that the generator could be the first electric machine to utilize these benefits commercially. The Air Force would benefit tremendously by implementing superconducting generators; mainly, for mobility and economic reasons.

Previous research has been limited to generators with superconducting field windings while employing conventional armature windings [35]. This is because field windings carry primarily direct current, which for superconductors results in lossless conduction; however, there have been several programs that consisted of a fully superconducting machine. In past year or so, there has been great strides made in the fabrication of high Tc ceramic superconducting coils; primarily, by the oxide powder in tube process [36-37]. This area of research is crucial if superconducting generators are someday going to replace conventional ac generators. Using high Tc ceramic superconductors allows cooling with liquid nitrogen rather than liquid helium, which is needed to get to the critical temperature (the point where a material becomes superconducting) of metallic superconductors. There are many advantages of using liquid nitrogen as a coolant (i.e. employing high Tc superconductors), and they will be discussed in section III.4, and should be looked into deeper.

This part of report uses information from scientific publications, reports from government agencies, opinions from experts at universities, government agencies, industries and Air Force. With the information attained it is possible to make an assessment for the feasibility of superconducting generators for use in the Air Force. When making the assessment the following criteria is the most relevant, and will be discussed in the following subsections: operational benefits (including size and weight), economic benefits, and reliability and maintainability.

III.2. Conventional and Superconductive Generators

III.2.1. Existing Air Base Generators

The conventional generators currently being employed in the Air Force have power ratings ranging from a few kW to several hundred MW, as seen in Figure 3 [38]. These are the ranges that are most important in this investigation, and will be considered in the feasibility study.

Specific weight of a generator is approximately 10-100 lb/kW [39]; and specific volume is approximately 0.02-0.05 m^3/kW [40]. To purchase and install a stationary generator, cost per kW is \$300 - \$ 350 in class A generator (750 kW range, full time usage, continuous operation). The cost will be approximately \$ 400 per kW for

a power plant generator (larger than 1 MW). To transport a generator via a cargo plane, cost is approximately \$0.0003 per pound per mile [41]. For a 1 MW generator, operating cost is \$0.072-\$0.0079 per kilowatt-hour; and maintenance cost is \$0.0002-\$0.0030 per kilowatt-hour. These values will be the basis for the evaluation and development of superconductive generators.

III.2.2. Conventional Generators

Conventional ac generators consist of two major parts: stator and rotor. The stator (or stationary part) usually consists of thin sheets of magnetic steel. The armature windings, which are made of copper coils and are inserted in stator slots, are the material in which the electricity is induced. The rotor (or rotating part) is made from stainless steel. The field windings, which are also made of copper coils, are inserted in the rotor slots and create a magnetic field through which the armature moves. This is done by supplying the field windings with an exciting current. The rotor is rotated by mechanical energy derived usually from a steam or water turbine. This will induce a voltage in the armature windings, and current can then be supplied to an electric load. If the field winding assembly is a rotor, the armature winding will be a stator or vice versa.

There are several limiting factors that exists in conventional generators. For example, very heavy magnetic iron is used for the stator core, which make transportation (if necessary) quite difficult. There exist many techniques to reduce weight/size, and to increase power generation efficiency. As an example, the field winding assembly can be replaced by a set of permanent magnets. As another example, electrical coil windings can be replaced in a cryogenic temperature environment, and resistive dissipation can be reduced.

A step-up transformer is also needed in conventional generators. This is needed to reduce energy loss when sending electricity over long distance. It reduces energy loss by increasing the voltage and decreasing current. The higher the current in a conductor, the greater the energy loss due to resistance. This power loss is of concern since it increases with the square of the current.

The stator core is at ground potential and each conductor needs to be insulated, and for this reason has a limiting voltage of approximately 26 kV [42]. In addition, armature slot-current densities are limited to approximately 300 A/cm^2 [43]. For generators to meet appropriate transient characteristics and voltage regulations, the reactive impedance of the armature windings (i.e. "synchronous reactance") must be held below a certain level. Therefore, the air gap between the rotor and stator needs to be larger than some minimum level. This stems from synchronous reactance being inversely proportional to the air gap [43]. Also, the exciting current should be increased, which in turn will increase the resistive loss in the field winding [44]. These relations to the air gap result in an overall reduction in operational efficiency. All of the above mentioned problems may be overcome, or reduced by employing a superconductive generator. Size and weight could be decreased, there would no longer be needed for a step-up transformer, larger current densities could be produced, energy consumption could be reduced, and greater performance could be resulted in.

III.3. Low Tc Metallic Superconducting Generators

Around the middle of the 1960's, the United States began extensive research efforts on superconducting generators. Soon after Japan, Europe, China and the former Soviet Union all had superconducting generator programs. Since then, different rotor/stator arrangements have been designed and tested. In earlier designs, the stator was made of a superconductive field winding and the rotor was a conventional armature [45]. In recent designs [46-47], the rotor has a superconductive field winding and the stator has a conventional armature, as illustrated in Figure 4 [48]. There exist several kinds of superconductive rotors; i.e. slow response type A, slow response type B and quick response type [49]. In some other designs, both windings are all superconductive [50-51].

In addition to the low Tc superconductor generators, we shall discuss high Tc generator in section III. 8. However, a brief description is given here for comparison. With the advent of high temperature superconductors in 1986 [51a] the potential for superconductor applications has increased greatly. This is mainly due to the higher operating temperatures (20-77 K), which results in reduced cooling costs when compared to low Tc superconductors (4.2 K). These factors result in machines that are even smaller and more economically viable than low Tc machines. The problem, as of right now, is being able to form the brittle ceramic superconductors into useful coils. These coils need to have current densities on the order of 10^5 A/cm^2 at 5T, and must be able to be supported structurally and chemically in the rotor or stator.

There has been great strides made recently in high Tc BiSrCaCuO ceramic coils, mainly by the oxide powder in tube process. Appendix II shows some characteristics of these wires produced at American Superconductor Corporation [38]. ASC has delivered motor coils that allowed Reliance Electric Company to demonstrate a two horse-power motor at liquid nitrogen temperatures [51b]. The company also plans to have a 1,000 meter wire by the end of the fiscal year [51c]. They have also developed a racetrack magnet that generates 0.30 T at 20K and it contains 300 meters of high Tc wire. These racetrack coils have demonstrated performance in an applications environment and are currently being developed for use in a 1 MW electrical generator for aerospace applications [38]. The many difficulties that are associated with the current carrying capabilities in the ceramic material (e.g., need to cross grain-boundaries and travel through individual grains) make research in this area crucial if these coils are going to be employed in the next generation of generators and motors. The Advanced Technology Program of the US Department of Commerce has given ASC $1.9 million over the next 3 years to develop these superconducting magnet coils.

III.3.1. United States Programs

The pioneers of superconducting generator research in the US have been Massachusetts Institute of Technology (MIT), General Electric (GE), and Westinghouse . Power levels of US experimental generators have been varied: 45 kVA in 1968, 5 MVA in 1972, 20 MVA in 1978, 50 MVA in 1990, and 300 MVA design goal in the mid 1980's [52-55].

III.3.1.1. MIT Program

In 1968, MIT build a 45 kVA generator that consisted of a superconducting field winding mounted on a rotor [56]. This led to the development of a 3 MVA generator in 1975 that was synchronized to the power system and used to produce reactive power. It operated for half an hour on a utility grid in Cambridge [57-59]. The experience with the previous two generators led to the development of a 10 MVA superconductive generator. This program was sponsored by the Department of Energy. This unit was expected to be capable of operating on a power system, which means that it must be stable, reliable, and able to operate through load unbalance and load transients [60-61].

The 10 MVA unit was comprised of the following components [60-61]:

a. cold rotor, all rotating elements (field winding, electrical shield, and damper winding) operate at liquid helium temperature.

b. field winding support, supported by a set of yokes between two torque tubes. Yokes transmit steady state torques from field winding to main rotor body, and also insulate winding from transient forces and torques.

c. damper winding, consists of two-phase (d-axis and q-axis) to provide torque required to damp out electromechanical oscillations, resulting from power system transient. D-axis winding provides little damping and is charted internally to the rotor. Q-axis winding provides majority of damping and requires additional series resistance to provide correct damping time constant.

d. shielding system, provides damping functions which protects field windings from transient magnetic fields. A copper shield ("can shield") is placed between damper and field windings for additional shielding.

e. cooling system, consists of two subsystems, i.e., cools field winding and damper winding. Under steady-state condition the two subsystems are connected in series with some helium flow. Under transient conditions a check-valve operates and isolates the subsystems.

f. helical armature winding, which is delta connected, helically wound and air-core winding, no end turns (saves a lot of space) and high voltage potential.

At operating conditions, the field windings carries 940 A and a peak magnetic flux density of 4.8 T. This unit has been tested for its electrical performance such as steady-state open and short circuit, and sudden short circuit. It was predicted that the no load field current was 803 A. The open circuit test results revealed that the production of higher order harmonics ($n>3$) was negligible. Some problems occurred with this unit and it was then rebuilt. The rebuilt unit showed nominal thermal performance and nominal electromagnetic performance. From the study of this unit it was found that something needs to be done, such as better insulating turn-turn connections which can survive the motors involved in making and insulating end connection; and a way of subjecting all stator insulation to meaningful tests must be planned [60-61].

III.3.1.2. GE Program

General Electric, in 1982, built a 20 MVA machine that produced real power to its complete rating [62]. This unit has undergone no-load tests and was connected in pump-back mode to produce real power to its full rating. This unit was strong enough to survive a fault without catastrophic rotor failure; however, could not survive a fault without "quenching".

In 1988 General Electric built a 20 MW generator, for light weight applications. This generator was driven by very low mass turbine similar to those used for liquid fuel rocket pumps. No transformer was used in this machine. The configuration of this generator is as follows. It consisted of a four pole configuration with a conductive stator shield and high rotor diameter. A conductive stator shield is lighter but less efficient than ferromagnetic shielding. The number of poles was increased to decrease mass and volume. Electrical efficiency was predicted at 91 % with losses of 2.59% of rating in conductive shield. Entire generator case needed to be intensively cooled. Current density of 1760 A/cm^2 was achieved by using a very efficient winding cross-section. For the next prototype the following is to be considered; torsional strength, dynamics, lateral vibrations of rotor, rotor shielding, rotor design for thermal insulation, armature and stator cooling and helium transfer to rotating frame [63].

III.3.1.3. Westinghouse Program

Westinghouse also has been quite active in R&D. In 1972, under no-load conditions, they built and tested a 5 MVA generator [64-65]. In 1980, with the support from the Electric Power Research Institute, they decided to design and construct a 300 MVA generator to be installed into the Gallatin power plant [66-67]. However, in 1983 the program was canceled, and a working generator was never completed, but some of their initial goals were.

III.3.2. Japan Program

Japan has been the only country with as an extensive program as the US. There are four major companies that manufacture generators in Japan, and they all have done at least some research into replacing conventional generators with superconducting generators. They are Fuji, Mitsubishi, Hitachi and Toshiba.

In 1972, a 30 kVA generator was developed and several other programs have been underway since [68-72]. The Japanese as of right now are in the midst of a very large national program that was started in 1988 [73]. This 8-year program under Super-GM (Engineering Research Association of Superconducting Generation Equipment and Materials) started out researching three different types of 70 MW class model machines (slow type A and B, and quick response type) which are different in characteristics and structure of superconducting field windings and rotor mechanical structure. Their aim is for a 200 MW class prototype. This will be part of the Moon-Light project of the Agency of Industrial Science and Technology of MITI (Ministry of International Trade and Industry). This is commissioned by the New Energy and Industrial Technology Development Organization, and consists of Hitachi Ltd., Mitsubishi Electric Corp., and Toshiba Corporation. So as can be clearly seen, Japan

has dedicated itself to develop and commercialize a superconducting generator in the near future. The United States needs to do the same thing, possibly implementing a national generator program [74], since after all we were the pioneers.

III.3.3. Europe

Europe has also combined industries with universities to add to their research effort. The University of Munich, in 1980, tested a 300 kVA machine [75]. Germany also has had programs from KWU (Kraftwerk Union). They consisted of a 120 MVA generator in 1987 to a 850 MVA design in 1993 [76]. However, the most important experiment is a large rotor, constructed at KWU, that is the diameter of a machine rated at 1000 MVA [77].

France's first work on superconducting generators was in Paris in 1965 on a 1 kW machine [78]. In addition, they constructed a freely spinning field winding rated at 500 kVA at the research institute in Grenoble in 1977 [79].

It is interesting to notice that a full superconductive generator can be achieved with both stator and rotor having superconducting windings. This has become possible with the development of ultra-fine NbTi filament wires [79a,79b]. A fully superconducting generator, as compared to a generator that consists of only a superconducting rotor, enhances the advantages seen in previous cryogenerators. Power density is increased by a factor of three, armature losses are reduced, efficiency is increased, and size and weight will be reduced [79c]. The synchronous reactances will be higher, reducing mechanical stresses and simplifying the generator design. These advantages that were foreseen allowed designs of fully superconducting generators to be built and tested.

III.3.3. Russia and China

Russia has had a superconducting program for quite a while [80]. In 1974 a 1.5 MVA machine was built and tested under no-load conditions. There have been some reports from visitors to the former USSR that have seen parts of the 300 MVA generator that was under construction in the 80's; however, published results from Russia are quite scarce. Currently, a 1200 MVA is under design.

In addition, China designed a 400 kVA generator in 1974, but their research besides that has been stagnant.

III.4. Operational Benefits

Operational benefits include technical and economical factors. Superconducting generators have many advantages over conventional generators.

III.4.1. Technical Factor

On the technical side, superconductive generators have the following advantages: high efficiency (>99.5% compared to 98.6%), light weight, small size, and long lifetime. Many of these advantages are due to elimination of the heavy magnetic iron that is used in conventional machines. Field windings made of niobium-titanium, for example, can achieve winding densities on the order of 10,000 A/cm^2, and this density is large enough that it is not necessary to enhance the magnetic flux with iron [81].

The main components of the superconducting generators are still the stator and rotor, however, the armature windings consist of an air-core structure. The advantages of this structure are numerous and are as follows:

1. A large reduction in the overall weight of the machine.
2. The size would also be decreased, since superconductors can develop much stronger magnetic fields, permitting the superconducting generator to be physically smaller for the same power output [82].
3. The inherent inductive reactance of the armature is greatly reduced, resulting in greater voltage regulation.
4. Since a greater amount of space is now available, the number of coil windings can be greatly increased.
5. Since there is no longer the magnetic steel, and therefore no longer a limiting voltage of 26 kV, the step-up transformer can be eliminated [83].

In addition to the above reasons for improved efficiency, efficiency improvements can be clearly seen in superconducting generators by some other facts. For example, the fact that there is no conduction loss in the superconducting field winding provides the machine with the largest gain in efficiency. Also, since the field achieved is higher, the length of the conductors in the armature can be reduced thus increasing efficiency by shortening the conduction path [84].

Beside efficiency, which is not always the number one priority, superconductive generators' lower weight and smaller size make the technology very attractive for Air Force usage. Conventional generators have specific weights on the order of 0.35 kg/kW [85]. Superconductive generators can produce more power for the same size machine because they can achieve such high flux densities; thus, specific weight is inherently reduced (0.01-0.03 kg/kW). Also, the specific volume is lower and gets much lower quite rapidly as the machines ratings get larger, as shown in Table 1. This is due to the fact that there is some minimum refrigeration requirement, but after the criteria is met, a higher rated generator does not require that much larger of a cryogenic system; therefore, it is generally believed that as of right now the benefits of superconducting generators clearly be seen at somewhat of high power (on the order of a few hundred MW), and there is some disagreement about the cost effectiveness of lower power ratings. But, it has to be remembered that this logic is based on conventional low Tc metallic superconductors. For the Air Force, because of the crucial factor of mobility, the overall reduction in size and weight (about 50%) should be a prime motivator to continue R&D efforts.

Other benefits that could possibly be seen by implementing superconductive generators are:

(1) improving voltage stability and power system stability in transient and steady states [86], and (2) increasing reliability. Reliability is an extremely important factor because of the economic value that is associated with it. There are several potential reliability features incorporated with superconducting generators as follows [87]:

1. Within the lifetime of the machines there will be very few thermal cycles due to the fact that the active parts of the rotor are maintained at one temperature for long periods.
2. The stator winding may be constructed on an integrated structure and be supported so that very little relative motion between the conductors, insulator, and structure, due to thermal changes will take place.
3. Critical fault clearing times are equal or superior to conventional generators without the need for field forcing during the fault period. This results in very simple low power excitation and regulating systems which could be very reliable.

Also, the elimination of the magnetic iron reduces the generator reactance, which will improve the stability characteristics [83].

There are many technical benefits associated with superconducting generators, as can clearly be seen. There are also many economic benefits that are direct results, and are the focus of the next section.

III.4.2. Economic benefits

When looking at the overall cost of a generator, three factors need to examined: capital cost, operational cost, and maintenance cost. Operational cost is the highest (~$0.079/kW-hr), with capital cost next (~$350/kW), and maintenance cost last (~$0.003/kW) [88]. The economic feasibility is tied to loss reduction in superconducting materials normalized to ambient temperatures (reducing wire loss and/or obtaining higher temperatures) [89]. Small gains in efficiency can result in a substantial reduction in capitalized losses. For example, a 1% increase in efficiency (which may be seen with superconducting generators) for a 1 MW generator over a 30 year life results in a saving of approximately $25 million.

Table 2 shows a cost comparison between a conventional, a low Tc superconducting, and a high Tc superconducting generator [90]. As can be seen, the capital cost of the superconducting generator may be higher (due to high material cost, the cryogenic system, magnetic shielding, etc.), but overall annual cost is much lower. This stems from the gain that is seen in efficiency, and therefore, a reduction in losses in the superconducting generator. The superconducting generator would be more cost effective even if the capital cost for the conventional generator were zero [84].

The majority of the cost of a generator is in the operation as stated above. A superconducting generator lowers the operational cost and the maintenance cost by a factor of three to four (as shown in a recent Westinghouse study). The lifetime of a conventional generator is short, and reliability is less. With these factors weighed out, superconducting generators are to be more effective. Also, since the maximum rating for superconducting generators is larger, the economy of scale can extend beyond that of conventional generators [90]. The Air Force also needs to look at the factor of transporting these generators (~$0.0003/lb-mile)[87]. Since the

superconducting generator will weigh less, another economic advantage is clearly seen. These facts prove that an initial investment in superconducting generators, in the long run, could be very cost effective.

Thus, overall cost of superconductive generator system is estimated to be lower than that of conventional generator [91]. As an example, let us consider a small operation 3,000 miles away for one year, supported by a new generator of 900 kW (40,000 lb). If a conventional generator is utilized, the overall cost will be $977,488, in which operation cost shares 62.4%. However, if a superconductive generator is utilized, the total cost will be $881,992.80; or 11.6% savings[88]. If the operation is longer than one year, there will be more savings. When 500-1,000 units are superconductive, the total savings will be $57,728,000-$115,456,000, or more [88]. Itemized costs are shown in Table 3, and the calculation are shown in Appendix 1 for generators of 900 kW and 1MW.

III.5. Problems and Limitations

In spite of the fact that superconducting technology is very promising, research and development efforts need to continue to investigate some of the following problems that have been associated with the previous generator programs. With superconducting generators, it is not possible to just replace the conventional copper windings with a superconducting winding; a different design is required. The following obstacles may or may not affect the feasibility of superconducting generators being applied to commercial usage, only further research can determine that.

Offsetting some of the efficiency benefits (~0.2%), is the need to cool the superconductor to operating temperatures. The energy required to get to the boiling point of liquid helium temperatures (4.2 K), and the complexity of the thermal system required results in a high cost. A portion of the complexity stems from superconductors having losses to time varying flux; therefore, there is a need to shield from negative sequence and time and space harmonic magnetic fields [84]. But, if the rotor is too well shielded, the machine loses the ability to damp swings of rotor speed relative to synchronous speed [92]. The rotor needs to be supported by torque tubes which have high torsional strength and low heat leak and be isolated from thermal conduction and radiation. This mechanical support is needed because during a terminal fault (or sudden short-circuit) the electromotive force on the damper shield tend to twist and crush it, and if this happens then the machine must be able of surviving it, and this means that the shield must be fairly thick (~20-25% its radius) [92]. This support is electrically inactive, therefore, the coupling between the field winding and the armature winding is reduced and this significantly reduces the machines performance.

Since the rotor turns at very fast speeds (3600 rpm), a small movement of the components would generate enough heat by friction to degrade the performance of the superconductor [93]. When ac flux density is generated by a copper magnet, ac losses in the superconductor is a result. In turn, the heat generated from these losses vaporizes the liquid helium around the superconductor [93]. At liquid helium temperatures, everything (excluding helium) is a solid. That means that contaminants such as air can cause blockage and interference [81].

When looking at the armature, even though it may be in a conventional in type, it needs to be uniquely built for superconducting generator. This is due to the fact that since the magnetic iron is removed, the conductors are exposed to full magnetic flux; thus, losses are seen by the diffusion currents and forces that are not normally seen in conventional machines. These windings must be provided with structure and cooling which is different from conventional ac generator armature designs [84].

Another major question is if and how superconducting generators will scale to other ratings. It is known that basic scaling laws for superconducting machinery are quite different from that of conventional machinery. It is also believed that superconducting generators scale well to larger machines and less well to smaller ratings [94], this is of concern to the air force if the data in Figure 3 is complete. Also, refrigeration systems need to be highly reliable, and relatively maintenance free.

When specifically speaking for airborne applications, some factors need to be taken into consideration. Generators for airborne missions must meet specific weight goals. For the air force it may be advantageous to trade some efficiency for weight consideration over a reasonable range. There are designs for smaller ratings that can achieve lower specific weight; although more difficult to achieve than at larger ratings. Some of the design considerations are [94]: selecting a higher speed (which usually accompanies smaller machines anyway), and a smaller rotor diameter should be used to shrink end regions and get lower end weights (however, this gives poorer mutual coupling between field and armature). As stated earlier, generator designs are somewhat dominated by the machine not being damaged by a suddenly applied short circuit. For the air force, since there is a limited duration of the mission (when on board) there is no possibility of repairing the major failed component (a major component is what usually fails when a terminal fault exists), and, therefore by eliminating this design constraint, a greater probability of finding a mechanically adequate machine will be seen [94].

Another consideration for airborne applications is the refrigeration. A very large amount of liquid helium is required on board an aircraft. A 20 MW generator will consume 20 l/hr of liquid helium [95]. Other problems associated with airborne cryogenic subsystems are [95]: 1) the supply from cryogenic source to base, 2) base supply (filling and standby operations), 3) airborne supply, 4) helium reclamation, and 5) reduced electrical breakdown potential when helium overflow or leak is present in the confined space of the aircraft.

As shown, there are many problems associated with superconducting generator technology, and even more limitations need to be considered when looking at airborne applications. Superconducting generator designs need to be carefully scrutinized to show what kind of machine will be adequate for each specific type of usage. This is why there is so much ongoing research on employing high Tc ceramic coils, hopefully, with this new technology many if not all of the above mentioned factors can be reduced or eliminated.

III.6.Recommended Program Development Approach

As far as air base are concerned, it is feasible to utilize superconductive generators with power ratings larger than 300 kW [96]. Development on high Tc superconductive wires and coils should continue.

Experimentation on existing low Tc superconductive generators should also continue. For example, there exists a 10 MW generator at MIT [97]. Its superconductive rotor field winding is workable, while its normal conductive stator armature winding is not [98]. An estimated cost to repair/remodel the unit is $200K- $300K. A joint sponsorship between DOD and DOE may allow further experimentation on this generator with low cost and low risk [99]. Based upon estimated saving [88], it is reasonable to invest one million dollars in Air Force R&D on superconductive generators.

III.7. From Low Tc to High Tc Generator

Generators employing low Tc metallic superconductors have been studied for almost 30 years throughout the world, and some great accomplishment have been made in this area.

As can be seen, there have been many superconducting generators designed, built and tested. A worldwide summary is given in Figure 5. The feasibility of superconducting generators is certainly there, but there are still areas that need to be probed into deeper. For example, the tests that have been done were on the order of only a couple of hours. Connection to a grid for production of real (as opposed to reactive) power has yet to be accomplished. Also, machines have not prevailed against sudden short circuits (terminal faults) and continued to operate. The possibility is definitely there, and maybe soon we can see drastic improvements in the operation of superconducting generators. A major stepping stone could be employing high Tc ceramic coils. This would make the entire superconducting machine much simpler, and many other advantages would be offered.

It is clear that using superconductors in the field windings of generators results in increased efficiency and performance, as has been discussed. The size and weight reduction is very attractive for Air Force considerations. The questions of cost are somewhat unclear, especially capital cost, but it is well documented that in the long run superconductive generators are going to be more cost effective than ones of conventional type. This is especially true for airborne applications.

The problem and limitations that have been discussed are being studied and progress is being made; however, research and development efforts are required so that a superconducting generator can be tested successfully for longer periods of time. When this happens the feasibility of employing these machines can be seen more clearly and realistically.

III. 8. High Tc Superconductive Generators

Much progress has been made in the low temperature superconductive generators. Due to its limitations such as very low operating temperature, a potentially more practical, high temperature superconductor is expected. The breakthrough of this type of superconductor which is usually made of oxide ceramics occurred in 1986.

There were several problems with the high Tc oxide ceramics in the beginning. For example, the copper oxide ceramics are brittle and have low current carrying capacity. In order to be useful practically, the

superconductor must be flexible, easy to produce and high current density. Moreover, any magnet or coil winding must be able to withstand the Lorentz forces and survive constant use in vibratory environment and endure thermal shock of cooling and warming cycles [100].

A recent report [100] showed that high-temperature superconducting coils and wires were capable of carrying 10,000 A/cm^2 at 77K over hundreds of meter The coils are 30 cm in length and racetrack in shape, manufactured by American Superconductor. American Superconductor under US Air Force sponsorship also develops coils as components of compact, light weight generators for airborne use. This coils also have racetrack-shape structure. This company has made the longest wire of high Tc superconductor and mostly does fabrication on bismuth (Bi-Sr-Ca-Cu-O) system [101].

Another company, Intermagnetic General Corporation also is doing some research on bismuth and thallium (Tl-Ba-Ca-Cu-O) systems. They can make a good wire from Bismuth superconductors, while they still have problem to make long thallium wire [101].

With this much progress it has been shown that application of high-temperature superconducting wire in generators has emerged, although further development is required and efficiency need to be optimized [100].

IV. Motor, Heat Pump, and Others

VI. 1. Motor

IV.1.1.Air Base Motors

Since motor inventory data were not available during this study, a telephone survey on large motors was conducted. At Arnold AFB, Tullahoma, TN, there exists approximately 150 units in 300 horse power (h.p.) range, 70 units in 300-500 h.p. range, 40 units in 500-700 h.p. range, and several units with power larger than 700 h.p. In a test lab of Wright-Patterson AFB, Dayton, OH, there exist 4 units in 450-600 h.p. range, 9 units in 1,000-2,000 h.p. range, 11 units in 2,100-5,500 h.p. range, and 3 units in 12,000-44,000 h.p. range.

IV.1. 2. Superconductive Motors

When a rotational machine is operating in generator/motor node, it is called alternator. There have been numerous studies on superconductive alternators [102]. Operational principles of a superconductive motor is similar to that of a superconductive generator, with a different energy conversion direction.

Since 1960's, various superconductive motors have been developed [103-104]. There exist several designs of superconductive motors: DC, synchronous, induction, induction/synchronous hybrid, reluctance, and homopolar inductor motors [105-107]. In addition to rotational motors, linear motors have been constructed and tested [108-109]. Since 1987, high Tc superconductor motors have been designed and demonstrated [110-112].

The first ac synchronous motor using high Tc superconducting coils and wires has been recently demonstrated [100]. This unit utilized high Tc superconductive coils and wire capable of carrying 10,000 A/cm^2 at

77 K over hundreds of meter as previously mentioned. This prototype has been built by Reliance Electric Company in Cleveland, Ohio. The coils used are 30 cm in length and racetrack-shaped, manufactured by American Superconductor. Two of the coils were used in a prototype of two pole, 1500 W (2 h.p.) ac synchronous motor, operated in liquid nitrogen at 3600 rpm [100].

IV.1. 3. Recommended Development Approach

A bench top demonstration unit based on high Tc superconductor should be constructed and tested. The construction may consist of two phases: 1. motor based on bulk superconductors; 2. motors based on superconductive coil windings. Phase 1 project can be an improvement on existing motor [113-114]. Phase 2 project can be divided into two steps: A. evaluation of high Tc superconductors and wires/coils; B. construction of motors. Step A may require one year to finish. Since initial part of Step A belongs to 6.1 category, funding from internal sources and AFOSR will be needed. Superconductors can be supplied by several sources [115] , and evaluated in different labs [116]. Step B may require two years, and experimentation should be carried out in one of the Air Force Labs.

VI.2. Heat Pump and Others

VI.2.1. Heat Pump

Heat pumps are widely used in air bases [117]. Requirements on advanced heat pumps include: 1. high mobility, 2. high efficiency, and 3. no pollution to environment. Existing heat pumps are based on vapor condensation and compression techniques, in which chlorofluorocarbon (CFC) refrigerants are known to deplete ozone. To protect environment, CFC is being replaced by other chemicals. However, long term environment impact of those chemicals has yet to be evaluated.

As compared to gas dynamic cycles in vapor condensation techniques, magnetic heat pump cycles have higher efficiency due to large transfer coefficient between heat transfer fluid and magnetic solid. In addition, magnetic heat pump will have smaller specific volume (cubic feet per unit thermal energy) than that of vapor condensation pumps

Before we describe magnetic heat pumps, let us review basic thermal cycles [118]. There exist four different thermal cycles: Stirling, Brayton, Carnot, and Ericsson cycles. In Figure 6, two phase diagrams of Ericsson cycle are illustrated. Figure 6(a) is a pressure-volume diagram ; and Figure 6 (b) is a temperature-entropy diagram. Heat is transferred to a working fluid during constant-pressure process 2-3, and during isothermal expansion process 3-4. Heat is rejected during constant-pressure process 4-1, and during isothermal compression process 1-2. Figure 7 illustrates an Ericsson cycle accomplished in a gas turbine engine, with a generator.

Operational principle of magnetic heat pump is based on an effect called magnetocaloric effect [119]. Thermodynamic cycles operate near Curie temperature of a magnetic medium material. Originally, magnetic alignment of each domain in the material is random, and net moment is zero. If a magnetic field is applied to the

material, every domain will have the tendency to align its moment along the applied field. Magnetic energy is transferred into thermal energy, and the material is heated. If the applied field is withdrawn, every domain will become randomly oriented, and the material is cooled. When this magnetocaloric effect is utilized in a thermal cycle, heat can be produced and transferred. There exist many publications on magnetic refrigeration systems with operational temperature below 20 K [119]. For the near room temperature operation (-40 C to + 40 C), there are two kinds of prototype systems: reciprocating and rotational motions [120]

Figure 8 shows a reciprocating magnetic heat pump, which consists of a magnet, a magnetic medium material, a regenerator, two heat exchanges, and two actuators [121-122]. The magnetic medium can be a ferromagnetic material such as gadolinium with Curie temperature of approximately 292 K [123]. Figure 9 is an entropy-temperature phase diagram of the thermal-magnetic process illustrated in Figure 8. Magnetization in Figure 9 corresponds to gas compression in Figure 6 (b).

To develop room temperature heat pumps for air bases, several problems need to be solved. Fisrt, to our best knowledge, there has been no systematic study on feasibility of the magnetic heat pumps [124]. Second, there has been no system design of a magnetic heat pump for air base applications. Third, there has been no experimentation on high Tc superconductor magnets for heat pumps. Fourth, there has been limited study on gadolinium and its compound.

Magnetic field strength required in heat pumps is typically several Tesla (T), e.g., 6-10 T. With the existing technologies, superconductive magnets are feasible to reach such field strength. (With normal conductors, electromagnets will be too large and heavy, which are not practical in heat pumps). Usually, low temperature metallic superconductors are utilized to fabricate electromagnetic coils.

High Tc superconductors were discovered several years ago, with superconductive transition temperature larger than 77 K. There are two critical magnetic fields, H_{c1} and H_{c2}. The value of H_{c1} is 10-100 Gauss (G), and the value of H_{c2} is estimated to be larger than 40T. Figures 10, magnetic field generated in superconductor coils is summarized. [125] The obtained magnetic field value, 1.75 T, is much lower than H_{c2}. We believe that our current work on BiSrCaCuO and TlBaCaCuO will allow us to produce higher magnetic field strength.

Existing problems include:

1. limited understanding of Gd and its compounds;
2. limited fabrication techniques;
3. limited measurement in magnetic field of 0-8 T;
4. limited knowledge on particle size effect, i.e. relationship between a critical value and particle size.

Existing data on magnetic materials are obtained with magnetic field of 8 T or less. It is desirable to fabricate particles of 20-50 nm, whose critical values are different from that of micrometer particles [130-131].

VI. 2. Superconductive Transformers

The basis of transformer technique is coils which have been utilized in SMES, generators, motors and magnets. So far, there has been no published result on the construction/test of a full scale power transformer. A 1 GVA transformer has been considered by DOE labs [132].

From available information, it is estimated that transformer power in air bases varies from several hundred kW to 50 MW [133]. To further study the feasibility and reliability of superconductive transformers, we suggest that a small scale transformer (200-700 kW) should be designed, built and tested.

VI.3. Superconductive Chokes

A choke is a coil which can limit current flow in a circuit of a power station or substation. Other names are; current limiter and reactor. It has been demonstrated that high Tc superconductors can be utilized as chokes [134]. An experiment should be conducted in an Air Force lab to study the reliability of the superconductive chokes.

VI. 4. Power Lines

Power lines are divided into transmission lines or distribution lines. In Air Force installations, the number of transmission lines are very limited, but the number of distribution lines are countless. A typical distribution line has a length of 25-30 miles, with the maximum current of approximately 1,000 amperes. All these characteristics are compatible to capabilities of high Tc superconductors, based on existing studies [135]. If all the distribution lines are buried underground, the reliability and security of Air Force power systems will be enhanced.

V. Conclusion and Discussion

Based on our studies following conclusions can be arrived: (1) Superconductive Magnetic Energy Storage (SMES) devices should be tested immediately; (2) Superconductive Generators of 1-10 MW should be developed as soon as possible; and (3) other devices such as motors and magnetic heat pumps should also be developed

Recently, GE has developed a cryogen free magnet, which can be used in SMES and generator and other devices to reduce construction cost, to ease maintenance cost, to reduce size and weight. For example, a superconductive stator can be built based on this magnet. Air Force should look into this technique in more detail.

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39. Data based on 750 kW bare base generator, 500-1,000 kW generators in several air bases, and 1-10 MW commercial products.

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135. EPRI, Pirelli Cable Co., Undergound Systems, Inc. Techniques will be: tapes, coatings of high Tc superconductor materials on copper tubes, and others.

Table 1. Specific volumes for different rated superconducting generators.

Power	Specific Volume (cm^3/kW)
18.5 kW	5,200
45 kW	2,340
5 MW	408
10 MW	22.9

Table 2. Cost comparison for a 300 MW generator (millions of 1989 dollars).

parameter	conventional generator	LTSC generator	HTSC generator
efficiency (%)	98.6	99.6	99.7
capital cost	880	1,240	740
annual capitalized losses	1,400	430	280
annual capital costs	165	230	140
total annual costs	1,565	660	420

Table 3. Itemized cost comparison between a conventional and a superconducting generator.

cost	capital	transport	operational	maintenance
conventional unit price	\$350/kW	\$0.0003/lb-mile	\$0.079/kW-hr	\$0.003/kW-hr
conventional total price	\$315,000	\$36,000	\$622,836	\$23,652
ratio of super/convention	1.5	0.6	0.6	0.6
superconducting total price	\$472,500	\$21,600	\$373,701.60	\$14,191.20

Appendix I. Calculations for a generator (SC and conventional), operating for 1 year, 3000 miles away.

Part A 900 KW

Conventional Generator Costs and Ratio of Superconducting to Conventional Costs

Capital	Transport	Operational	Maintenance
$350/kW	$0.0003/lb-mile	$0.079/kW-hr	$0.003/kW-hr
1.5	0.6	0.6	0.6

Conventional Generator Cost Calculations

capital	($350)(900kW) / (kW)	=	$315,000
transport	($0.0003)(40,000 lbs)(3000 mi) / (lb-mile)	=	$36,000
operational	($0.079)(900 kW)(8760 hr) / (kW-hr)	=	$622,836
maintenance	($0.003)(900 kW)(8760 hr) / (kW-hr)	=	$23,652
	TOTAL		**$997,488**

Superconducting Generator Costs Calculations

capital	($315,000)(1.5)	=	$472,500
transport	($36,000)(0.6)	=	$21,600
operational	($622,836)(0.6)	=	$373,701.60
maintenance	($23,652)(0.6)	=	$14,191.20
	TOTAL		$881,992.80

% SAVINGS = 1- 881,992.80/997,488 = ***11.57***%

Part B Calculation for 1 MW generator

Table B-1. Itemized cost comparison between a conventional and a superconducting generator.

cost	capital	transport	operational	maintenance
conventional unit price	$350/kW	$0.0003/lb-mile	$0.079/kW-hr	$0.003/kW-hr
conventional total price	$350,000	$36,000	$692,040	$26,280
ratio of super/convention	1.4	0.5	0.6	0.6
superconducting total price	$490,000	$18,000	$415,224	$15,768

Conventional Generator Costs and Ratio of Superconducting to Conventional Costs

Capital	Transport	Operational	Maintenance
$350/kW	$0.0003/lb-mile	$0.079/kW-hr	$0.003/kW-hr
1.4	0.5	0.6	0.6

Conventional Generator Cost Calculations

capital	($350)(1000kW) / (kW)	=	$350,000
transport	($0.0003)(40,000 lbs)(3000 mi) / (lb-mile)	=	$36,000
operational	($0.079)(1000 kW)(8760 hr) / (kW-hr)	=	$692,040
maintenance	($0.003)(1000 kW)(8760 hr) / (kW-hr)	=	$26,280
		TOTAL	**$1,104,320**

Superconducting Generator Costs Calculations

capital	($315,000)(1.4)	=	$490,000
transport	($36,000)(0.5)	=	$18,000
operational	($622,836)(0.6)	=	$415,224
maintenance	($23,652)(0.6)	=	$15,768
		TOTAL	$938,992

% SAVINGS = 1-938,992/1,104,320= *14.97*%

Appendix II. Long Length Performance of High Tc Composite Wires at 77K and Self Field.

length (m)	Ic (A), (1μV/cm)	Jc (A/cm^2), (1μV/cm)	Ic (A), (10^{-11} ohm-cm)	Jc (A/cm^2), (10^{-11} ohm-cm)
44	20.8	17,500	17.7	15,000
99	17.2	14,500	14.4	12,250
300	15.3	13,000	12.4	10,500

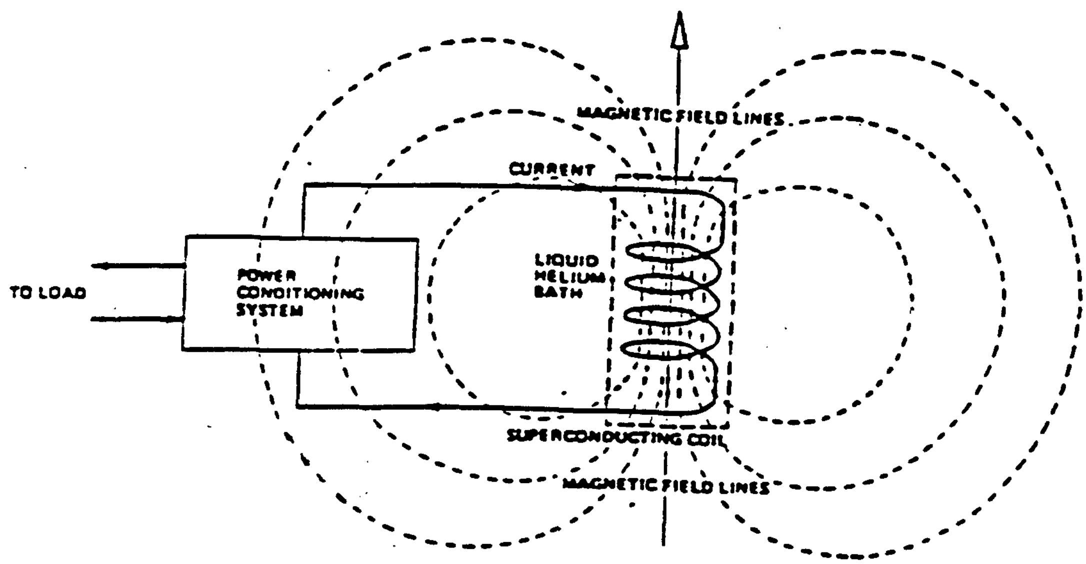
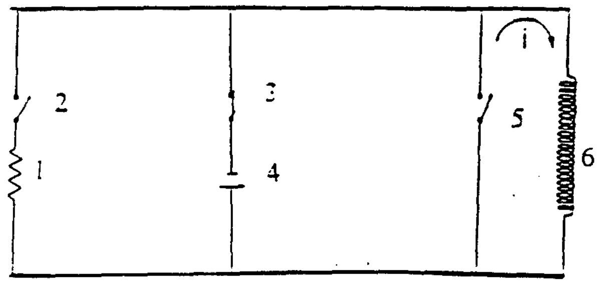
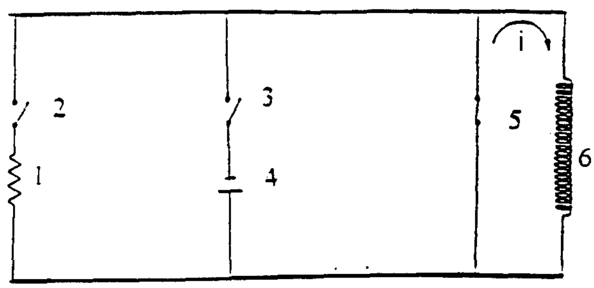


Figure 1: Basic unit of a SMES

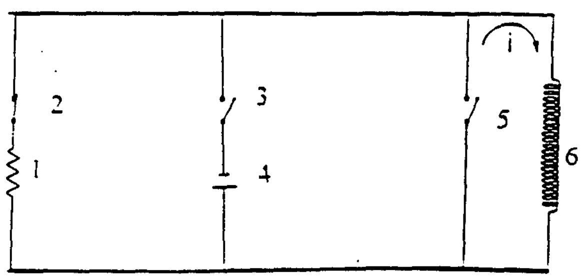


(a) Charging Mode



(b) Persistent Current Mode

1. Load
2. Load switch
3. Power source switch
4. Power source
5. Persistent current switch
6. Superconducting coil



(c) Discharging Mode

Figure 2: Basic electrical circuit of a SMES

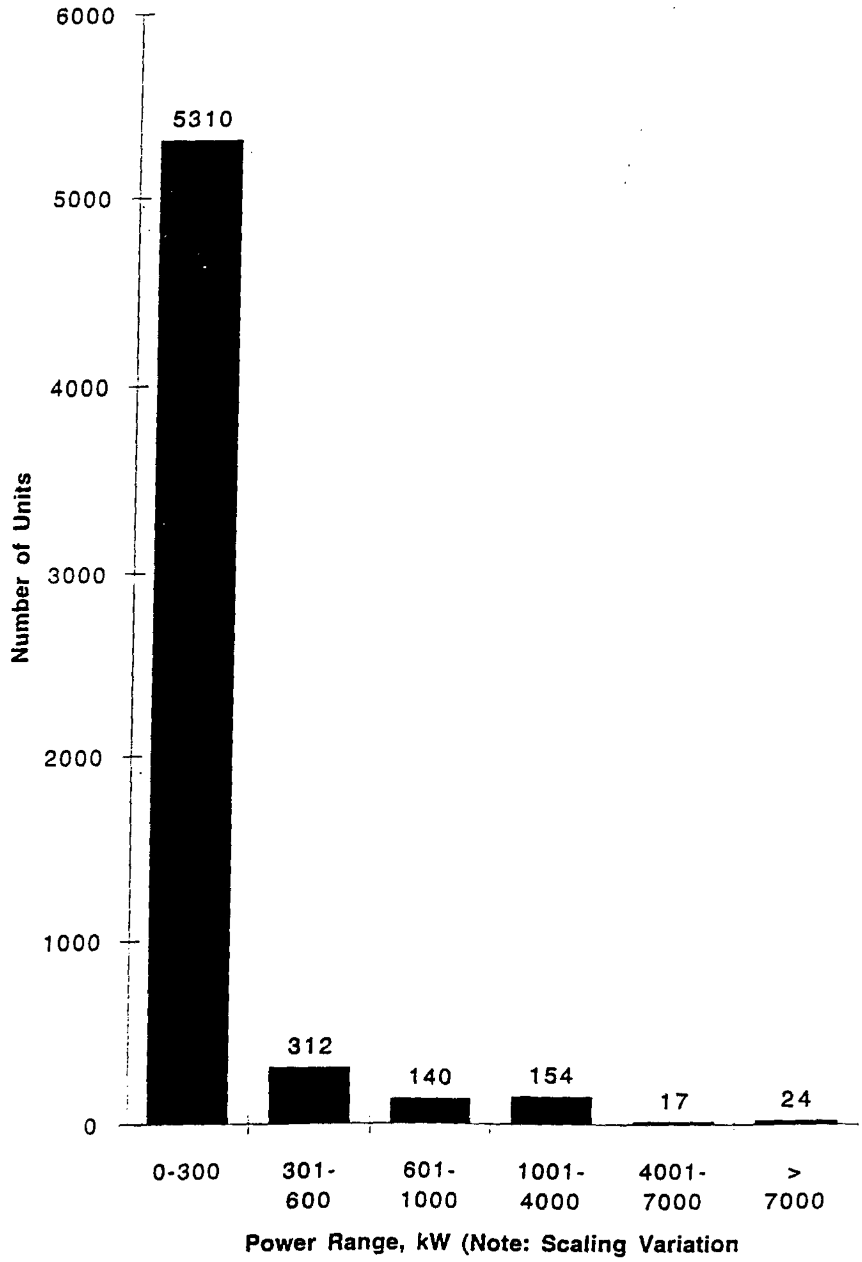


Figure 3: Number of Units vs. Generator Power

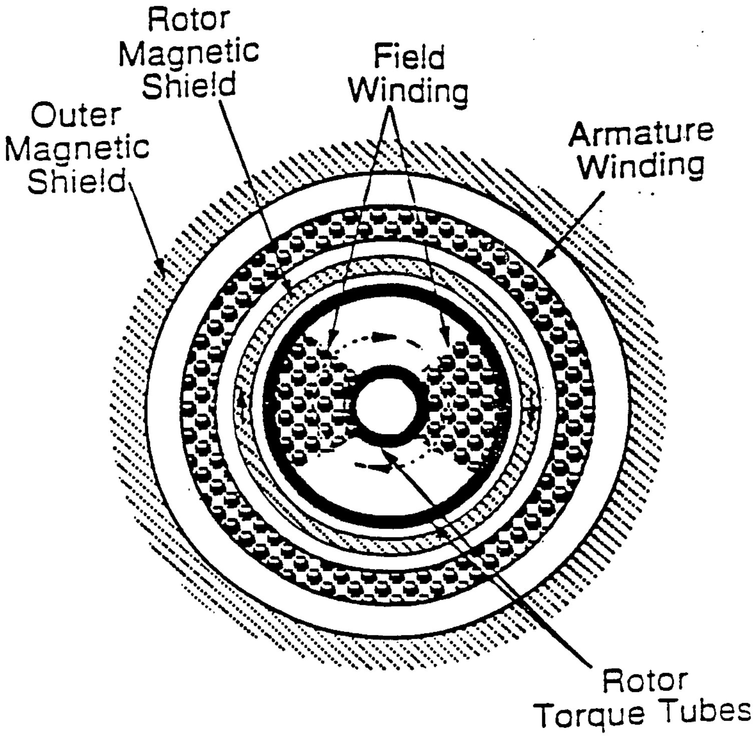


Figure 4: Superconductive Generator

SC Generator Programs vs. Year

	USA	Japan	Germany	France	Former USSR	China
1965	8 kW (AVCO)			1 kW (Paris)		
	50 kW (Dynatech)					
	45 kVA (MIT)					
1970					20 kVA	
	3 MVA (MIT)	30 kVA				
	5 MVA (West.)	4 MVA				
		10 kVA			1.5 MVA	
1975						400 kVA
		6.2 MVA (Fuji-Mit.)		500 kVA (Grenoble)	200 kW	
					2 MW	
1980	300 MVA (We/EPRI)	20 MVA (Fuji)	300 kVA (Munchen)			
		50 MVA (Hitachi)				
	20 MVA (GE)					
		3 MVA (Toshiba)			20 MW	
1985						
	10 MVA (MIT)					
	20 MVA (GE)		120 MVA (KWU)	20 kVA (Grenoble)	300 MVA	
		100 kVA (Toshiba)			5 kVA	
1990		20 kVA	400 MVA (KWU)	20 kVA (Grenoble)	1200 MVA	
	20 MVA (MIT)	3 x 70 MW class				
			850 MVA			
1995						
	1 MW (West) proposed	Moonlight Project 200 MW Class				
2000						

Fully Superconducting Generator (i.e. SC armature)

Figure 5: Superconductor programs vs. Year

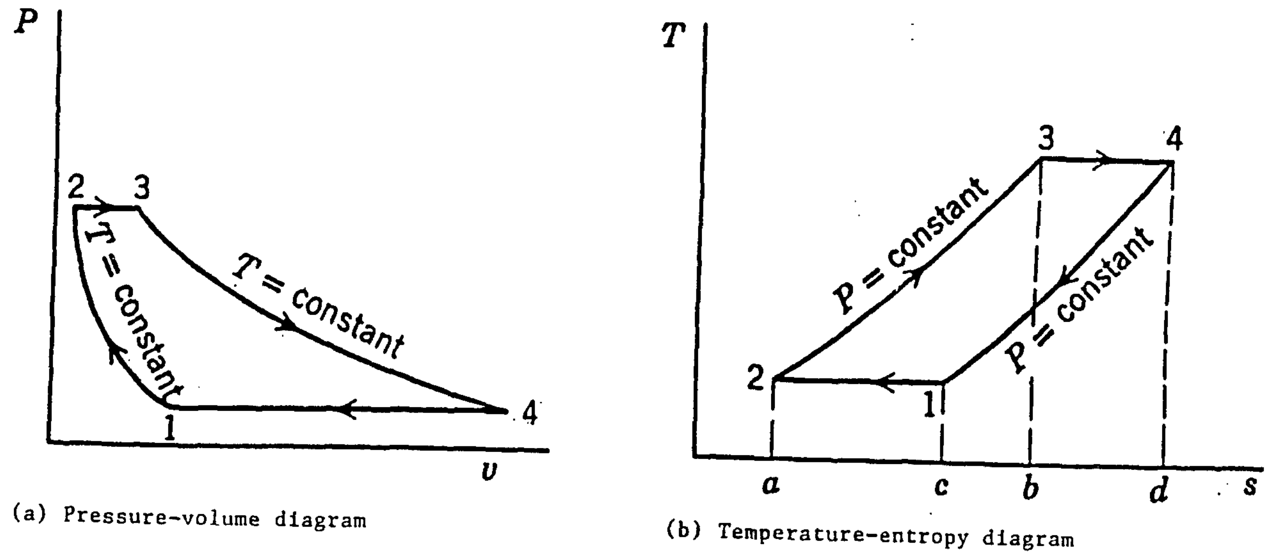


Figure 6: Phase diagrams

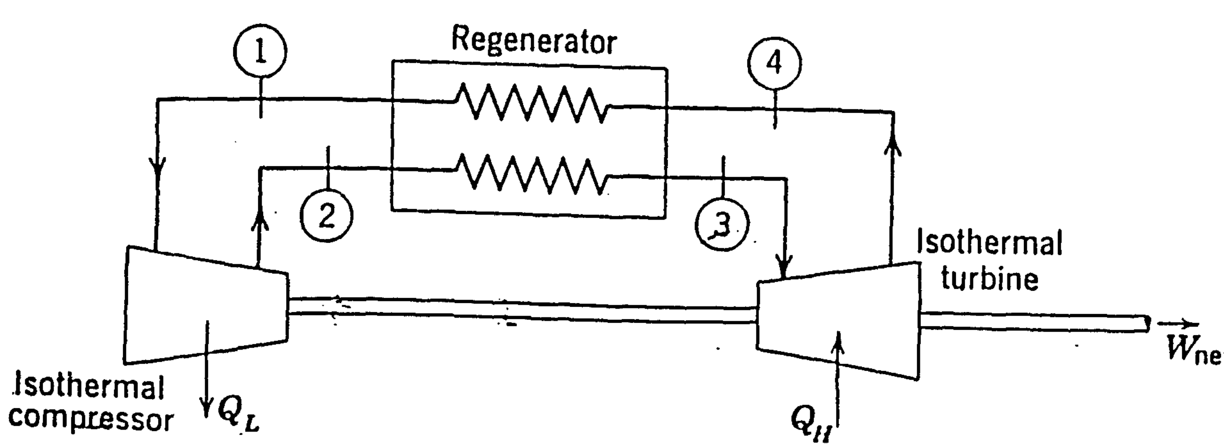


Figure 7: Conventional heat pumps with gas compressor

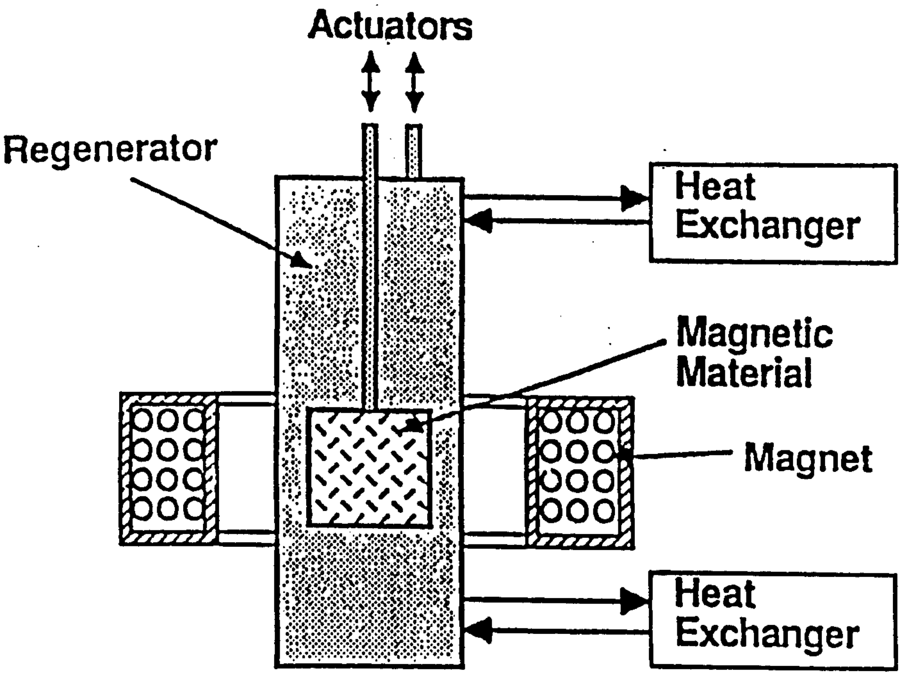


Figure 8: Illustration of magnetic heat pump

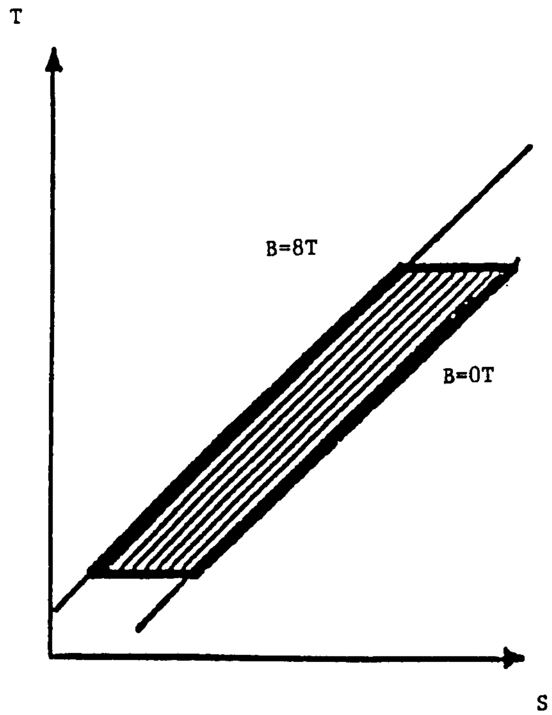


Figure 9: Temperature-entropy phase diagram

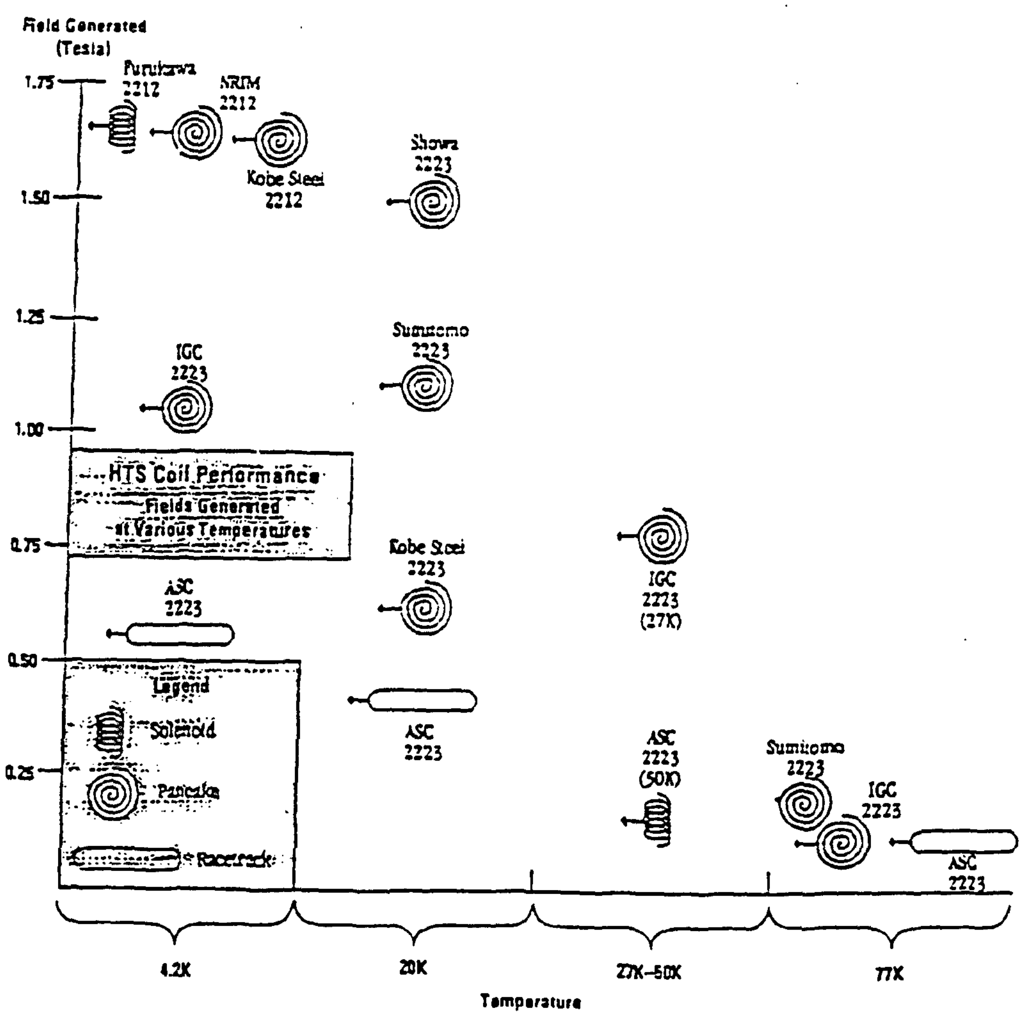


Figure 10: Magnetic field generated in high Tc superconductor coil